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(54) Wave filter having two or more coaxial dielectric resonators in juxtaposition

(57) A radio frequency filter having at least two dielectric resonators (1,2) in juxtaposition, each resonator including a tubular dielectric body (3a,3b). Formed on the dielectric body (3a,3b) of each resonator are an inner (4a,4b) and an outer (5a,5b) conductors and various other conductors including a terminal conductor (8a,8b) for connection of the filter to external circuity. In order to assure positive isolation of the terminal conductors (20a,20b) of both resonators from each other, the outer conductors (5a,5b) are provided with extensions (17a, 17b) which intervene between the terminal conductors (8a,8b) for preventing them form being capacitively coupled together.

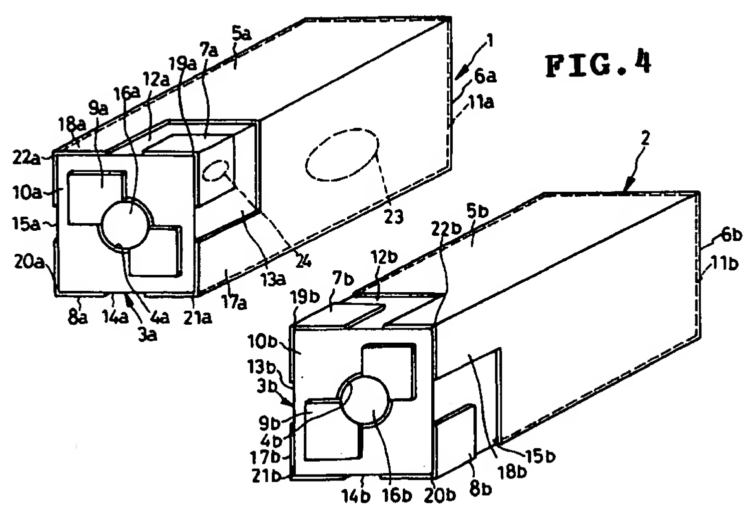

FIG. 4

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Description

The present invention relates generally to wave filters, and deals more specifically with radio frequency filters of the kind comprising two or more coaxial, dielectric resonators in juxtaposition. The radio frequency filters according to the invention find typical applications in mobile or portable telephone sets, although no unnecessary limitations thereto are intended.

Bandpass or bandstop radio frequency filters have been known which typically take the form of a pair of juxtaposed coaxial dielectric resonators operating in transverse electromagnetic (TEM) mode, as disclosed for example in U.S. Pat. No. 5,578,975 to Kazama et al. Methods have also been known of capacitively coupling together the dielectric resonators. One such known method, according to Japanese Unexamined Pat. PUb. No. 7-176911, teaches to provide layers of electrically conductive material on the opposed surfaces of the resonators, thereby obtaining capacitances between the conductive layers and the inner conductors of the resonators, and to solder or otherwise join the conductive layers. These conductive layers are referred to as resonator coupling conductors.

The dielectric resonators have been further provided with additional conductor layers on their outer surfaces for use as terminals in connecting the filter to external circuits. These terminals should of course be electrically isolated from each other as much as possible. Difficulties have been encountered, however, in realizing a desired degree of isolation between the terminals because they have been capacitively coupled together in devices composed of juxtapositions of two or more dielectric resonators.

Additional problems left unsolved with dielectric resonator wave filters arise from the presentday demand for smaller and smaller devices. The outer conductor of each resonator is provided with extensions to one end of the dielectric body according to one known downsizing method, and, according to another such method, the inner conductor is joined directly to a conductive layer, or inner conductor extension, formed on one end of the dielectric body.

Such known downsizing methods are alike in aiming at lower resonance frequencies with each dielectric body maintained at the same length as before. This objective, known as the wavelength shortening effect, is obtained as the capacitance between the extensions of the outer conductor and the inner conductor, or between the extension of the inner conductor and the outer conductor, of each resonator is connected in parallel with the resonance circuit of each resonator proper, resulting in a decrease in resonance frequency. For example, the resonance frequency of a device having a pair of dielectric resonators may decrease from 1900 megahertz, in the case where no such downsizing measures are taken, to as low as 1000 megahertz when the noted capacitance additionally connected in parallel with the resonance circuit of each resonator is 20 picofarads.

Let us now consider a wave filter comprised of juxtaposed dielectric resonators having the inner conductor extensions, the terminal conductors, and the resonator coupling conductors. Capacitances between resonator coupling conductors and inner conductors and capacitances between terminal conductors and inner conductors change with the size of the inner conductor extensions. The aforesaid wavelength shortening effect is therefore not adjustable by the inner conductor extensions without affecting the capacitances in question.

The terminal conductors and the resonator coupling conductors have presented a further problem. These conductors have been required to be of not less than a certain size for providing the desired capacitances, running counter to the size reduction of the filters incorporating them.

A yet further problem with dielectric filters in general has been the spurious resonance at thrice the fundamental frequency or thereabouts. The spurious resonance has resulted in insufficient attenuation of that higher harmonic.

Embodiments of the present invention aim to improve isolation between the terminal conductors in wave filters having two or more dielectric resonators in juxtaposition.

Another aim is to make readily adjustable the wavelength shortening effect of wave filters of the kind defined, with little or no influence on capacitances between resonator coupling conductors and inner conductors or on capacitances between terminal conductors and inner conductors.

Yet another aim is to reduce the sizes of the terminal conductors and the resonator coupling conductors in wave filters of the kind defined.

A further aim is to overcome the spurious resonance that has heretofore occurred at about thrice the fundamental frequency in wave filters of the kind defined, and hence to make possible the attenuation of that harmonic frequency.

The invention is defined in the independent claim, appended hereto, to which reference should now be made.

Briefly, the invention concerns a dielectric wave filter having at least two dielectric resonators in juxtaposition. Each dielectric resonator comprises a dielectric body having a plurality of side surfaces between a pair of opposite end surfaces, and a resonance hole extending between the pair of end surfaces. An inner conductor covers an inner surface of the dielectric body whereas an outer conductor covers those parts of the side surfaces of the dielectric body which are contiguous to one of the end surfaces of the dielectric body. The outer conductors on both dielectric bodies are joined to each other both mechanically and electrically. A shorting conductor covers said one end surface of the dielectric body and so electrically interconnects the inner and the outer conductors. Also formed on each dielectric body are a res-

onator coupling conductor covering part of at least that side surface of each dielectric body which confronts the other dielectric body, and a terminal conductor covering part of the side surfaces of each dielectric body and disposed adjacent the other of the end surfaces thereof. The resonator coupling conductors on both dielectric bodies are joined to each other both mechanically and electrically. The terminal conductors on both dielectric bodies are disposed at least on those side surfaces of the dielectric bodies which face away from each other. The invention particularly features an outer conductor extension extending from the outer conductor on each dielectric body toward said other end surface thereof, the outer conductor extensions on both dielectric bodies being disposed at least on those side surfaces of the dielectric bodies which confront each other, thereby intervening between the terminal conductors on both dielectric bodies.

Thus the terminal conductors of the two dielectric resonators are better isolated from each other than heretofore by the outer conductor extensions intervening therebetween. Experiment has proved that little or no signal leakage occurs from the input to the output terminal conductors in filters constructed according to this invention.

The outer conductor extensions on the dielectric bodies serve the additional purpose of providing the wavelength shortening effect by virtue of capacitances between them and the inner conductors. The wavelength shortening effect makes it possible to provide smaller size filters.

Preferably, the inner conductor of each resonator is also provided with an extension. Disposed on said other end surface of each dielectric body, the inner conductor extensions function to make the wavelength shortening effect even more pronounced.

The outer conductor extensions may be so patterned as to provide greater inductances for attenuating the third harmonic of the fundamental frequency.

The invention may be carried into practice in various ways, but embodiments will now be described by way of example only with reference to the accompanying drawings, in which:

FIG. 1 is an end elevation of a first preferred form of dielectric wave filter according to an embodiment of the present invention;
FIG. 2 is a top plan of the **FIG. 1** filter;
FIG. 3 is a longitudinal section through the **FIG. 1** filter, taken along the line *A-A* in **FIG. 1**;
FIG. 4 is an exploded perspective view of the **FIG. 1** filter;
FIG. 5 is a left hand side elevation of the left hand resonator of the **FIG. 1** filter;
FIG. 6 is a bottom plan of the left hand resonator of the **FIG. 1** filter;
FIG. 7 is a left hand side elevation of the right hand resonator of the **FIG. 1** filter;
FIG. 8 is a bottom plan of the right hand resonator of the **FIG. 1** filter;
FIG. 9 is an end elevation of the left hand resonator of the **FIG. 1** filter, the view being explanatory of the arrangement of the inner conductor extension on the end surface of the dielectric body;
FIG. 10 is a sectional view showing the **FIG. 1** resonators as mounted on a circuit board, the resonators being shown sectioned along the line *B-B* in **FIG. 2**;
FIG. 11 is a top plan of the **FIG. 10** circuit board;
FIG. 12 is an equivalent circuit diagram of the **FIG. 1** filter;
FIG. 13 is a graph plotting the curve of the gain of the **FIG. 1** filter against the input frequency;
FIG.14 is an end view of a dielectric resonator having a modified inner conductor extension according to another embodiment of this invention;
FIG.15 is an end view of a dielectric resonator having another modified inner conductor extension according to another embodiment of this invention;
FIG. 16 is an end view of a dielectric resonator having still another modified inner conductor extension according to another embodiment of this invention;
FIG. 17 is an end view of a dielectric resonator having a further modified inner conductor extension according to another embodiment of this invention;
FIG. 18 is a top plan of another preferred form of dielectric filter according to another embodiment of this invention;
FIG. 19 is an end elevation of the **FIG. 18** filter;
FIG. 20 is an equivalent circuit diagram of the **FIG. 18** filter;
FIG. 21 is an end elevation of still another preferred form of dielectric filter according to another embodiment of this invention;
FIG. 22 is a section through one of the resonators of the **FIG. 21** filter, taken along the line *C-C* in **FIG. 21**;
FIG. 23 is an exploded perspective view of the **FIG. 21** filter;
FIG. 24 is an axial section through one of the dielectric resonators of the **FIG. 21** filter, the view showing a step in the fabrication of the filter;
FIG. 25 is a view similar to **FIG. 24** but showing another step in the fabrication of the **FIG. 21** filter;
FIG. 26 is a top plan of yet another preferred form of dielectric filter according to another embodiment of this invention;
FIG. 27 is an exploded perspective view of the **FIG. 26** filter;
FIG. 28 is a left hand side elevation of the left hand resonator of the **FIG. 26** filter;
FIG. 29 is a bottom plan of the left hand resonator of the **FIG. 26** filter;
FIG. 30 is a left hand side elevation of the right hand resonator of the **FIG. 26** filter;
FIG. 31 is a bottom plan of the right hand resonator

of the **FIG. 26** filter;

FIG. 32 is an equivalent circuit diagram of the **FIG. 26** filter;

FIG. 33 is a side elevation of a dielectric resonator having a modified outer conductor and a modified extension therefrom according to another embodiment of this invention;

FIG. 34 is a side elevation of a dielectric resonator having another modified outer conductor and a modified extension therefrom according to another embodiment of this invention;

FIG. 35 is a side elevation of a dielectric resonator having still another modified outer conductor extension according to another embodiment of this invention;

FIG. 36 is a bottom plan of the **FIG. 35** resonator;

FIG. 37 is a exploded perspective view of a further preferred form of dielectric filter according to another embodiment of this invention;

FIG. 38 is an exploded perspective view of a further preferred form of dielectric filter according to another embodiment of this invention;

FIG. 39 is an end elevation of a further preferred form of dielectric filter according to another embodiment of this invention;

FIG. 40 is a top plan of a further preferred form of dielectric filter according to another embodiment of this invention;

FIG. 41 is a section through the **FIG. 40** filter, taken along the line *D-D* in **FIG. 40**;

FIG. 42 is an exploded perspective view of the FIG. 40 filter;

FIG. 43 is a top plan of a still further preferred form of dielectric filer according to another embodiment of this invention; and

FIG. 44 is an exploded perspective view of the **FIG. 43** filter.

The present invention will now be described more specifically in terms of its first preferable embodiment illustrated in **FIGS. 1-13**. The representative filter is broadly comprised of two TEM mode, coaxial dielectric resonators 1 and 2 seen in **FIGS. 1-4**. The resonators 1 and 2 are alike in comprising dielectric bodies 3*a* and 3*b*, inner conductors 4*a* and 4*b*, outer conductors 5*a* and 5*b*, shorting conductors 6*a* and 6*b*, resonator coupling conductors 7*a* and 7*b*, terminal conductors 8*a* and 8*b*, inner conductor extensions 9*a* and 9*b*, first outer conductor extensions 17*a* and 17*b*, and second outer conductor extensions 18*a* and 18*b*.

The dielectric bodies 3*a* and 3*b* are substantially tubular in shape, preferably square in cross section. each having a first end surface 10*a* or 10*b*, a second end surface 11*a* or 11*b*, a first side surface 12*a* or 12*b*, a second side surface 13*a* or 13*b*, a third side surface 14*a* or 14*b*, and a fourth side surface 15*a* or 15*b*. A resonance hole 16*a* or 16*b* extends longitudinally through each dielectric body 3*a* or 3*b*, between the first 10*a* or 10*b* and second 11*a* or 11*b* end surfaces.

The inner conductors 4*a* and 4*b* of the resonators 1 and 2 line the walls bounding the resonance holes 16*a* and 16*b* in the dielectric bodies 3*a* and 3*b*, whereas the outer conductors 5*a* and 5*b* cover the four side surfaces 12*a* and 12*b*, 13*a* and 13*b*, 14*a* and 14*b*, and 15*a* and 15*b* of the dielectric bodies. The shorting conductors 6*a* and 6*b* are formed on the second end surfaces 11*a* and 11*b* of the dielectric bodies 3*a* and 3*b*, interconnecting the inner 4*a* and 4*b* and outer 5*a* and 5*b* conductors.

The resonator coupling capacitors 7*a* and 7*b*, through which the two resonators 1 and 2 are coupled together, are formed on parts of the dielectric body first 12*a* and 12*b* and second 13*a* and 13*b* side surfaces. The terminal conductors 8*a* and 8*b* are formed on parts of the dielectric body third 14*a* and 14*b* and fourth 15*a* and 15*b* side surfaces. The outer conductor first extensions 17*a* and 17*b* are formed on parts of the dielectric body second 13*a* and 13*b* and third 14*a* and 14*b* side surfaces. The outer conductor second extensions 18*a* and 18*b* are formed on parts of the dielectric body first 12*a* and 12*b* and fourth 15*a* and 15*b* side surfaces.

FIG. 1 best illustrates that the two resonators 1 and 2 are juxtaposed with the dielectric body second side surfaces 13*a* and 13*b* oriented toward each other. The resonators 1 and 2 are coupled together, both mechanically and electrically, by an electroconductive bonding agent such as solder joining those parts of the outer conductors 5*a* and 5*b* and resonator; coupling conductors 7*a* and 7*b* which overlie the dielectric body second side surfaces 13*a* and 13*b*. **FIG. 4** indicates the electroconductive bonding agent by the dashed lines designated 23 and 24. The layers of the bonding agent are so thin, however, that they are not shown in **FIGS. 1** and **2**.

The geometry of the various conductors on the dielectric bodies 3*a* and 3*b* will now be explained in more detail. The inner conductors 4*a* and 4*b*, first of all, thoroughly cover the dielectric body surfaces defining the resonance holes 16*a* and 16*b*. The shorting conductors 6*a* and 6*b* also completely cover the dielectric body second end surfaces 11*a* and 11*b*.

The outer conductors 5*a* and 5*b* cover all but parts of all the dielectric body side surfaces 12*a*-15*a* and 12*b*-15*b*, the remaining parts, left exposed by the outer conductors 5*a* and 5*b*, being contiguous to the dielectric body first end surfaces 10*a* and 10*b*. The outer conductor first extensions 17*a* and 17*b* extend from the outer conductors 5*a* and 5*b* onto mutually adjoining subparts of the noted remaining parts of the dielectric body second 13*a* and 13*b* and third 14*a* and 14*b* side surfaces, terminating at the dielectric body first end surfaces 10*a* and 10*b*. The outer conductor second extensions 18*a* and 18*b* likewise extend from the outer conductors 5*a* and 5*b* onto mutually adjoining subparts of the noted remaining parts of the dielectric body first 12*a* and 12*b* and fourth 15*a* and 15*b* side surfaces, terminating at the dielectric body first end surfaces 10*a* and 10*b*.

The resonator coupling conductors 7*a* and 7*b* are

formed on subparts of the noted remaining parts of the dielectric body first 12*a* and 12*b* and second 13*a* and 13*b* side surfaces, lying contiguous to the dielectric body first end surfaces 10*a* and 10*b* and spaced from all of the outer conductors 5*a* and 5*b* and the first 17*a* and 17*b* and second 18*a* and 18*b* extensions therefrom. It is to be noted that those parts of the resonator coupling conductors 7*a* and 7*b* which overlie the dielectric body first side surfaces 12*a* and 12*b* occupy less than half the width (horizontal dimension as viewed in **FIG. 1**) of these dielectric body first side surfaces. Similarly, those parts of the resonator coupling conductors 7*a* and 7*b* which overlie the dielectric body second side surfaces 13*a* and 13*b* occupy less than half the width (vertical dimension in FIG. 1) of these dielectric body second side surfaces.

The terminal conductors 8*a* and 8*b* are formed on subparts of the noted remaining parts of the dielectric body third 14*a* and 14*b* and fourth 15*a* and 15*b* side surfaces, lying contiguous to the dielectric body first end surfaces 10*a* and 1*b* and spaced from all of the outer conductors 5*a* and 5*b* and the first 17*a* and 17*b* and second 18*a* and 18*b* extensions therefrom. Those parts of the terminal conductors 8*a* and 8*b* which overlie the dielectric body third side surfaces 14*a* and 14*b* occupy less than half the width (horizontal dimension in **FIG. 1**) of these dielectric body third side surfaces. The remaining parts of the terminal conductors 8*a* and 8*b*, overlying the dielectric body fourth side surfaces 15*a* and 15*b*, also occupy less than half the width (vertical dimension in **FIG. 1**) of these dielectric body fourth side surfaces.

Thus, those parts of the outer conductor first extensions 17*a* and 17*b* which overlie the dielectric body second side surfaces 13*a* and 13*b* are in register, via the dielectric bodies 3*a* and 3*b*, with those parts of the terminal conductors 8*a* and 8*b* which overlie the dielectric body fourth side surfaces 15*a* and 15*b*. So interposed between the two terminal conductors 8*a* and 8*b*, which are to function respectively as input and output terminals, the outer conductor first extensions 17*a* and 17*b* serve to prevent the terminal conductors from being capacitively coupled together, thereby electrically isolating them from each other.

An inspection of **FIGS. 1** and **4** in particular will reveal that the resonator coupling conductors 7*a* and 7*b* and terminal conductors 8a and 8*b*, as well as the outer conductor first 17*a* and 17*b* and second 18*a* and 18*b* extensions, are configured in axial symmetry about the axes of the resonance holes 16*a* and 16*b*. The two dielectric resonators 1 and 2 can therefore be of identical make; only, they are coupled together with one resonator angularly displaced 90 degrees about the resonator axis from the other.

Before studying the inner conductor extensions 9*a* and 9*b* in detail, let us specify the four corners the dielectric bodies 3*a* and 3*b* as follows: the first corner 19*a* and 19*b* between the dielectric body first 12*a* and 12*b* and second 13*a* and 13*b* side surfaces, the second corner 20*a* and 20*b* between the dielectric body third 14*a* and 14*b* and fourth 15*a* and 15*b* side surfaces, the third corner 21*a* and 21*b* between the dielectric body second 13*a* and 13*b* and third 14*a* and 14*b* side surfaces, and the fourth corner 22*a* and 22*b* between the dielectric body first 12*a* and 12*b* sand fourth 15*a* and 15*b* side surfaces.

The inner conductor extensions 9*a* and 9*b* may be thought of as being each composed of two separate parts of virtually square shape, extending from the inner conductor 4*a* and 4*b* toward, and terminating short of, the third 21*a* and 21*b* and fourth 22*a* and 22*b* corners of the dielectric body first end surfaces 10*a* and 10*b*. The arrangements of the inner conductor extensions 9*a* and 9*b* are such that they are each of bilateral symmetry both about a first diagonal line between the first 19*a* and 19*b* and second 20*a* and 20*b* corners and about a second diagonal line between the third 21*a* and 21*b* and fourth 22*a* and 22*b* corners.

FIG. 9 shows the geometry of the various conductors on the dielectric body first end surface 10*a* of only the first dielectric resonator 1, it being understood that the conductors on the dielectric body first end surface 10*b* of the second resonator 2 is of like arrangement. As indicated in this figure, the shortest distance *La* between resonator coupling conductor 7*a* and inner conductor extension 9*a*, and the shortest distance *Lb* between terminal conductor 8*a* and inner conductor extension 9*a*, are both longer than either of the shortest distance L_1 and L_2 between inner conductor extension 9*a* and outer conductor extensions 17*a* and 18*a*. The same dimensional relations apply, of course, to the conductors on the dielectric body first end surface 10*b* of the second dielectric resonator 2.

Further the inner conductor extensions 9*a* and 9*b* are so shaped, sized, and arranged that capacitances between inner conductor extensions 9*a* and 9*b* and resonator coupling conductors 7*a* and 7*b*, and capacitances between inner conductor extensions 9*a* and 9*b* and terminal conductors 8*a* and 8*b*, are both less than capacitances between inner conductor extensions 9*a* and 9*b* and outer conductor first 17*a* and 17*b* and second 18*a* and 18*b* extensions.

All the conductors on the dielectric bodies 3*a* and 3*b*, the inner conductors 4*a* and 4*b*, outer conductors 5*a* and 5*b*, resonator coupling conductors 7*a* and 7*b*, terminal conductors 8*a* and 8*b*, inner conductor extensions 9*a* and 9*b*, and outer conductor first 17*a* and 17*b* and second 18*a* and 18*b* extensions, can be formed by coating a pasted electroconductive material such as silver on the required parts of the dielectric bodies 3*a* and 3*b* and then by firing the coatings. Alternatively, the conductors on the dielectric bodies 3*a* and 3*b* may be created first by covering the complete surfaces of the dielectric bodies with a conductive material, either by coating and firing or by plating, and then by removing unwanted parts of the coatings or platings either by laser beam irradiation or by a cutting tool.

Constructed and coupled together as in the forego-

ing, the pair of dielectric resonators 1 and 2 are usually mounted on a printed circuit board shown at 25 in both **FIGS. 10** and **11**. The circuit board 25, itself of electrically insulating material, has printed on its major surface a grounding conductor layer 26 and two terminal conductor layers 27 and 28.

The grounding conductor layer 26 on the circuit board is generally in the shape of the capital T, having a first limb 26*a* for contact with the outer conductors 5*a* and 5*b* of both resonators 1 and 2, and a second limb 26*b* for contact with the outer conductor first extensions 17*a* and 17*b* of both resonators 1 and 2. The terminal conductor layers 27 and 28 are intended for contact respectively with the terminal conductors 8*a* and 8*b* of both resonators 1 and 2 and so shaped and sized as to fit those parts of the terminal conductors 8*a* and 8*b* which overlie the dielectric body third side surfaces 14*a* and 14*b*.

The resonators 1 and 2 are positioned on the circuit board 25 as indicated by the broken lines in **FIG. 11**. So positioned, the resonators are affixed to the circuit board 25 as by solder 29, **FIG. 10**, joining the outer conductors 5*a* and 5*b* and their extensions 17*a* and 17*b* to the grounding conductor layer 26, and the terminal conductors 8*a* and 8*b* to the terminal conductor layers 27 and 28.

Since the two dielectric resonators 1 and 2 of this representative wave filter are of like construction, either of the two terminal conductors 8*a* and 8*b* thereon can be an input, and the other an output. The same applies to the two terminal conductor layers 27 and 28 on the circuit board 25. Also, notwithstanding the showings of **FIGS. 10** and **11**, the circuit board 25 may be variously modified to permit various other circuit components to be mounted thereon.

Reference is now directed to **FIG. 12**, an equivalent circuit diagram of the representative filter set forth above, for a discussion of the electrical details of the device. Terminals T_1 and T_2 in this diagram represent the terminal conductors 8*a* and 8*b* on the dielectric bodies 3*a* and 3*b*, or the terminal conductor layers 27 and 28 on the circuit board 25. Capacitors C_1 and C_4 represent the capacitances between terminal conductors 8*a* and 8*b* and inner conductors 4*a* and 4*b* together with their extensions 9*a* and 9*b*. Capacitors C_2 and C_3 represent the capacitances between resonator coupling conductors 7*a* and 7*b* and inner conductors 4*a* and 4*b* together with their extensions 9*a* and 9*b*. Capacitors Ct_1 and Ct_2 represent the sums of the capacitances between inner conductor extensions 9*a* and 9*b* and outer conductor extensions 17*a*, 17*b*, 18*a* and 18*b* and the capacitances between outer conductor extensions 17*a*, 17*b*, 18*a* and 18*b* and inner conductors 4*a* and 4*b*, *La*, *Lb*, *Ca* and *Cb* represent the resonators proper of the two dielectric resonators 1 and 2. Connected in parallel with the parallel circuits of *Ca* and *La* and of *Cb* and *Lb*, respectively, the capacitors Ct_1 and Ct_2 function to achieve the aforementioned wavelength shortening effect.

At *A* in the **FIG. 13** graph is plotted the frequency characteristic of the above described representative wave filter. The main resonance peak *P0* occurs at the fundamental frequency *f0*, providing a passband. The spurious resonance peak *P1* occurs at slightly below the frequency 3*f0*, the third harmonic of the fundamental frequency *f0*.

Were it not for the outer conductor first 17*a* and 17*b* and second 18*a* and 18*b* extensions, the stray capacitances and stray inductances between resonator coupling conductors 7*a* and 7*b* and ground would be so low that the peak of the spurious resonance would remain virtually unaffected. The resulting filter characteristic would then be as indicated by the dashed line labeled *B* in **FIG. 13**, failing to sufficiently attenuate the third harmonic 3*f0*.

By contrast, thanks to the provision of the outer conductor first 17*a* and 17*b* and second 18*a* and *18b* extensions, the stray capacitances between resonator coupling capacitors 7*a* and 7*b* and ground become so high that, in coaction with the stray inductances, they serve to lower the peak frequency of the spurious resonance from *B* to *A* in **FIG. 13.** Such stray capacitances and stray inductances are indicated at *Cs* and *Ls* in **FIG. 12**.

Possibly, some wave filters fabricated according to this invention may fail to offer the desired characteristics. Such failures are easy to occur because the dielectric bodies 3*a* and 3*b* take the form of ceramic moldings, which are notoriously susceptible to dimensional instability, and, as a natural consequence, because the various conductors on the ceramic bodies are just no less subject to errors in shape, size or position. The following remedies are possible in such cases.

If the resonance frequency *f0* is lower than the desired one, either the outer conductors 5*a* and 5*b* may be cut shorter, or either or both of the inner conductor extensions 9*a* and 9*b* and the outer conductor extensions 17*a*, 17*b*, 18*a* and 18*b* may be cut off to required extents. For decreasing the capacitances of the capacitors C_2 and C_3 in **FIG. 12**, parts of the resonator coupling capacitors 7*a* and 7*b*, preferably their corners adjacent the outer conductors 5*a* and 5*b*, may be removed. Similarly, for decreasing the capacitances of the capacitors C_1 and C_4, parts of the terminal conductors 8*a* and 8*b*, preferably their corners adjacent the outer conductors 5*a* and 5*b*, may be removed.

In order to change the limit frequencies *f1* and *f2* in **FIG. 13**, the pattern of the grounding conductor layer 26, **FIG. 11**, on the circuit board 25 may be altered as indicated by the arrows. The limit frequencies *f1* and *f0* will come closer to the resonance frequency *f0* if the grounding conductor layer 26 is made smaller for less contact with the outer conductors 5*a* and 5*b*, and go away from the resonance frequency *f0* if the grounding conductor layer is made larger for greater contact with the outer conductors.

The following is a summary of the advantages gained by the wave filter set forth above with reference to **FIGS. 1-13**:

1. Interposed between the terminal conductors 8*a* and 8*b*, as best depicted in **FIG. 10**, the outer conductor first extensions 17*a* and 17*b* function to shield the terminal conductors from each other, minimizing signal leakage from input to output. On the circuit board 25, too, the terminal conductor layers 27 and 28 are isolated from each other by the part 26*b* of the grounding conductor layer 26.
2. As the outer conductor first 17*a* and 17*b* and second 18*a* and 18*b* extensions and inner conductor extensions 9*a* and 9*b* provide the capacitors Ct_1 and Ct_2, **FIG. 12**, a lower resonance frequency is obtainable for the same length of the dielectric bodies 3*a* and 3*b*. In other words, a smaller filter is obtainable for a given resonance frequency.
3. The inner conductor extensions 9*a* and 9*b* are spaced from the resonator coupling capacitors 7*a* and 7*b* and terminal conductors 8*a* and 8*b*, so much so that little or no change in capacitances therebetween will occur even if the inner conductor extensions are formed displaced to the positions indicated by the dashed lines in **FIG. 9.** In this case, moreover, the distances L_1 between inner conductor extensions 9*a* and 9*b* and outer conductor extensions 18*a* and 18*b* will shorten whereas the distances L_2 between inner conductor extensions 9*a* and 9*b* and outer conductor extensions 17*a* and 17*b* will grow, but the sum of the distances L_1 and L_2 will be the same as if the inner conductor extensions are formed in the proper positions indicated by the solid lines. In short the filter will suffer no substantial change in characteristics from such displacement of the inner conductor extensions.
4. With the noted decrease in capacitances between inner conductor extensions 9*a* and 9*b* and resonator coupling conductors 7*a* and 7*b*, and those between inner conductor extensions and terminal conductors 8*a* and 8*b*, these resonator coupling conductors and terminal conductors can be made so large in size, for given values of the capacitors *C1-C4*, **FIG. 12**, as to permit easy and positive coupling of the resonators to each other and to external circuits.

Embodiment of FIG. 14

Embodiments shown in **FIGS. 14-17** are all alike in featuring inner conductor extensions of various modified shapes. Although these figures show only first dielectric resonators 1*a*- 1*d*, it is understood that each of these resonators are to be combined, in the manner set forth in connection with the first disclosed embodiment, with another resonator of similar design to make up a filter in accordance with the invention. It is also understood that the resonators 1*a*-1*d* are identical with the above described resonators 1 and 2 in details other than the inner conductor extensions.

The **FIG. 14** resonator la has an inner conductor extension $9a_1$ which is similar to its counterpart 9*a* of the **FIG. 1** or **9** resonator 1 except that its two constituent portions of square shape are formed to include series of teeth 31 along their edges adjacent the outer conductor extensions 17*a* and 18*a*. These teeth are intended to be selectively removed for adjustment of the frequency characteristics of the filter.

Embodiment of FIG. 15

The **FIG. 15** resonator 1*b* features an inner conductor extension $9a_2$ in the shape of two strips each bent at three spaced points into an approximately square shape. So shaped, the inner conductor extension $9a_2$ function as both inductance element and capacitor. Consequently, the equivalent electric circuit of a filter comprised of two such dielectric resonators 1*b* needs modification of the **FIG. 12**. showing into one such that the capacitors Ct_1 and Ct_2 are connected, via inductance elements, in parallel with the *Ca-La* and *Cb-Lb* parallel circuits, respectively.

Embodiment of FIG. 16

The **FIG. 16** rrrresonator 1*c* features an inner conductor extension $9a_3$ having two portions of circular shape in places of the square shaped portions of the inner conductor extension 9*a* of the **FIG. 1** or **9** resonator 1. The circular extensions perform the same functions as do the square or rectangular shaped ones.

Embodiment of FIG. 17

The **FIG. 17** resonator 1*d* features an inner conductor extension $9a_4$ in the shape of a band with tapering ends. Essentially, this extension $9a_4$ is akin to the **FIG. 1** or **9** extension 9*a* except that the pair of square shaped portions of the latter are directly joined to each other. The double taper band extension $9a_4$, or an elliptic extension indicated by the dashed line in **FIG. 17**, perform the same functions as do the square or rectangular shaped ones.

Embodiment of FIGS. 18-20

The wave filter seen in **FIGS. 18** and **19** differs from all the foregoing embodiments in having three dielectric resonators in juxtaposition. For an easier understanding of this embodiment, the filter may be considered to have a third dielectric resonator 30 interposed between two resonators 1 and 2 of the same construction as in **FIGS. 1-13**.

The third or intermediate resonator 30 is similar to the other two resonators 1 and 2 in having a dielectric

body 3*c* with a resonance hole 16*c* extending therethrough, an inner conductor 4*c* lining the surface of the resonance hole, an outer conductor 5*c* covering the outer surfaces of the dielectric body, leaving exposed their parts adjoining the dielectric body first end surface 10*c*, and a shorting conductor 6*c* on the dielectric body second end surface 11*c*. The third resonator 30 does, however, differ from the other two in having no terminal conductors and, instead, in having two resonator coupling conductors 7*c* and 7*d*, instead of one in each of the other two resonators, and an inner conductor extension 9*c* and outer conductor extension 17*c* which are both different in shape from their corresponding parts of the other two resonators.

The two resonator coupling conductors 7*c* and 7*d* are formed on subparts of the noted exposed parts of the top and both sides, as viewed in **FIG. 19**, of the dielectric body 3*c*. The inner conductor extension 9*c* is formed on part of the lower half, as seen in **FIG. 19**, of the dielectric body first end surface 10*c*. The outer conductor extension 17*c* overlies the bottom surface and lower parts of the opposite side surfaces of the dielectric body 3*c*.

The three resonators 1, 2 and 30 are coupled together, both mechanically and electrically, by solder or like conductive bonding agent joining their outer conductors 5*a*, 5*b* and 5*c* and their resonator coupling conductors 7*a*, 7*b*, 7*c* and 7*d*.

Electrically, the three resonator filter of **FIGS. 18** and **19** is configured as diagramed in **FIG. 20**. The capacitance *Cc* and inductance *Lc* in this diagram represent the resonance circuit due to the inner conductor 4*c* and outer conductor 5*c* of the middle resonator 30, and the capacitance Ct_3 is due to the inner conductor extension 9*c* and outer conductor extension 17*c* and intended for the wavelength shortening effect. The capacitance C_5 represents that between the inner conductor 4*c* and resonator coupling conductor 7*c* of the middle resonator 30, and the capacitance C_6 that between the inner conductor 4*c* and resonator coupling conductor 7*d* of the middle resonator. The other electrical details of this filter are the same as those of the first disclosed device, as has been set forth with reference to **FIG. 12**.

It will be appreciated that the inner conductor extension 9*c* is spaced the greatest possible distance away from the resonator coupling conductors 7*c* and 7*d* in the third resonator 30. This positional relationship provides the same advantages as those pointed out in connection with the first embodiment.

Embodiment of FIGS. 21-23

The wave filter seen in **FIGS. 21-23** is similar to the **FIGS. 1-13** filter in having a pair of dielectric resonators 1*e* and 2*e* coupled together, so that the **FIGS. 21-23** device will be best understood by comparison with the **FIGS. 1-13** one. **FIG. 21** corresponds to **FIG. 1**, **FIG. 22** to **FIG. 3**, and **FIG. 23** to **FIG. 4**.

Constructionally, the resonators 1*e* and 2*e* of the **FIGS. 21-23** filter are similar to the resonators 1 and 2 of the **FIGS. 1-13** device except the following two points:

1. The resonators 1*e* and 2*e* have no inner conductor extensions; instead, the resonance holes 16*a* and 16*b* are constituted of smaller diameter portions 32*a* and 32*b* and larger diameter portions 33*a* and 33*b* in axial alignment.
2. All the conductors 4*a*, 4*b*, 5*a*, 5*b*, 6*a*, 6*b*, 7*a*, 7*b*, 8*a*, 8*b*, 17*a*, 17*b*, 18*a* and 18*b* of the resonators 1*e* and 2*e* are of two layers, as indicated by way of example at 36 and 37 in **FIG. 22** for the outer conductor 5*a* of the resonator 1*e*.

The larger diameter portions 33*a* and 33*b* of the resonance holes 16*a* and 16*b* lie next to the first end surfaces 10*a* and 10*b* of the dielectric bodies 3*a* and 3*b*, and the smaller diameter portions 32*a* and 32*b* next to the second end surface 11*a* and 11*b*. The axial dimension of the resonance hole larger diameter portions 33*a* and 33*b* is greater than the dimensions of the resonator coupling conductors 7*a* and 7*b* and of the terminal conductors 8*a* and 8*b* in the axial direction of the resonance holes 16*a* and 16*b*. Consequently, the distance between the resonator coupling conductors 7*a* and 7*b* and the inner conductor portions 35*a* and 35*b* lining the resonance hole larger diameter portions 33*a* and 33*b* is wholly less than the distance between the outer conductors 5*a* and 5*b* and the inner conductor portions 34*a* and 34*b* lining the resonance hole smaller diameter portions 32*a* and 32*b*.

From the foregoing positional and dimensional relations it is possible to make greater the capacitances C_1, C_2, C_3 and C_4 in **FIG. 12**. In cases where such larger capacitances are not needed, the resonators 1*e* and 2*e* may be made more compact through size reduction of the resonator coupling conductors 7*a* and 7*b* and terminal conductors 8*a* and 8*b*. The provision of the resonance hole larger diameter portions 33*a* and 33*b* serves the additional purpose of improving the wavelength shortening effect.

According to the second recited feature of the **FIGS. 21-23** filter, all the conductors 4*a*, 4*b*, 5*a*, 5*b*, 6*a*, 6*b*, 7*a*, 7*b*, 8*a*, 8*b*, 17*a*, 17*b*, 18*a* and 18*b* of the resonators 1*e* and 2*e* are each of two layers, the baked-on first layer *36* and the plated-on second layer *37*. Typically, the first layer *36* is formed by coating a silver paste on the required parts of the dielectric bodies 3*a* and 3*b* and firing the coatings. A metal is then plated on the silver layers. The two-layer conductors serve to improve the electrical characteristics of the filter through reduction of their resistances, besides enhancing the mechanical strength.

FIGS. 24 and **25** are explanatory of a preferred method of creating the two-layer conductors on the dielectric bodies 3*a* and 3*b*, taking, however, only the dielectric body 3*a* for example. A silver paste may first be printed not only on those parts of the surfaces of the

dielectric body 3*a* where the conductors 4*a*, 5*a*, 6*a*, 7*a*, 8*a*, 17*a* and 18*a* are to be formed, but also on the first end surface 10*a* of the dielectric body. Then the printings may be fired, thereby forming the first layers 36 of the inner conductor 4*a*, outer conductor 5*a*, shorting conductor 6*a*, resonator coupling conductor 7*a*, terminal conductor 8*a*, and outer conductor extensions 17*a* and 18*a*, as well as of an additional conductor on the dielectric body first end surface 10*a*, as illustrated in **FIG. 24.** Then the second layers 37 may be formed on the first layers 36 by barrel plating, a known type of electroplating method, as in **FIG. 25.**

The resonance hole larger diameter portion 33*a* is relatively small in area. However, since the first conductor layer 36 preformed on this portion is joined via that on the dielectric body first end surface 10*a* to the first conductor layers of the resonator coupling conductor 7*a*, terminal conductor 8*a*, and outer conductor extensions 17*a* and 18*a*, the total area of these first conductor layers is large enough to permit the second conductor layer to be favorably created thereon by barrel plating.

Then the conductor layers on the dielectric body first end surface 10*a* may be ground off to complete the first dielectric resonator 1*e* shown in **FIGS. 21**and **22.** The second resonator 2*e*, being of exactly the same construction as the first 1*e*, can be fabricated by exactly the same method.

As an alternative method of fabricating the **FIGS. 21-23** filter, the **FIG. 24** article may be coupled to another such article. Then the second conductor layers 37, **FIG. 25**, may be plated on the first conductor layers 36 of both articles that have been coupled together. Then the conductor layers 36 and 37 may be ground off the dielectric body first end surfaces 10*a* and 10*b* of both articles, thereby completing the **FIGS. 21-23** filter.

This alternative method offers the advantage that the removal of the conductor layers 36 and 37 from the dielectric body first end surfaces 10*a* and 10*b* can be practically concurrent with the fine tuning of the resonance frequency through grinding of the dielectric body first end surfaces.

Embodiment of FIGS. 26-32

The resonators 1*f* and 2*f* of the **FIGS. 26-32** filter are akin to the resonators 1 and 2 of the **FIGS. 1-13** filter except for the following two dissimilarities:

1. The inner conductor extensions 9*a* and 9*b* and outer conductor second extensions 18*a* and 18*b* of the **FIGS. 1-13** resonators 1 and 2 are both absent from the **FIGS. 26-32** resonators 1*f* and 2*f*.
2. The remaining outer conductor extensions 17*a* and 17*b*, referred as the first extensions in the **FIGS. 1-13** filter, of the **FIGS. 26-32** resonators 1*f* and 2*f* are recessed at 40*a*, **FIG. 27**, and 40*b*, **FIG. 30.**

As will be understood from both **FIGS. 27** and **30,** the recesses 40*a* and 40*b* are formed in those parts of the outer conductor extensions 17*a* and 17*b* which overlie the dielectric body second side surfaces 13*a* and 13*b*, and lie next to the outer conductors 5*a* and 5*b*. The dimension of the recesses 40*a* and 40*b* in a direction parallel to the resonance hole axis is less than that of the outer conductor extensions 17*a* and 17*b*, so that the outer conductor extensions on the dielectric body second side surfaces 13*a* and 13*b* are comprised of a constricted neck 41*a* or 41*b* and a head 42*a* or 42*b*. The outer conductor extension heads 42*a* and 42*b* are the same as the resonator coupling conductors 7*a* and 7*b* and terminal conductors 8*a* and 8*b* in dimension in a direction parallel to the resonator hole axis. The heads 42*a* and 42*b* intervene between the terminal conductors 8*a* and 8*b*, effectively isolating them from each other.

The conductor patterns on the dielectric body third or bottom surfaces 14*a* and 14*b* are as pictured in **FIGS. 29** and **31.** A comparison of these figures with **FIGS. 6** and **8** will show that the bottom conductor patterns of the **FIGS. 26-32** resonators 1*f* and 2*f* are the same as those of the **FIGS. 1-13** resonators 1 and 2. The resonators 1*f* and 2*f* may therefore be mounted to the circuit board 25, **FIGS. 10** and **11**, by the same method as are the resonators 1 and 2.

In **FIG. 32** is given the equivalent electric circuit diagram of the **FIGS. 26-31** filter, in which parts having their counterparts in the **FIG.12** diagram are designated by like indicia. Inductance *Ls'* shown connected in series with capacitance *Cs* includes components due to the necks 41*a* and 41*b* of the outer conductor extensions 17*a* and 17*b*, therefore, the **FIG. 32** inductance *Ls'* is greater than the **FIG. 12** inductance *Ls*.

Like the **FIG. 12** capacitance C_3, the **FIG. 32** capacitance C_3 is due to the resonator coupling conductors 7*a* and 7*b* and outer conductor extensions 17*a* and 17*b*. Since the outer conductor extension heads 42*a* and 42*b* are the same as aforesaid with the resonator coupling conductors 7*a* and 7*b* in dimension in a direction parallel to the resonance hole axis, the **FIG. 32** capacitance C_3 is approximately equal to the **FIG. 12** capacitance *Cs*.

The capacitances Cg_1 and Cg_2 seen in **FIG. 32** represent those between terminal conductors 8*a* and 8*b* and outer conductor extensions 17*a* and 17*b*. **FIG. 12** omits the showing of these capacitances.

As indicated by the dot-and-dash curve *C* in **FIG. 13**, the peak P_1 of the spurious resonance of the **FIGS. 26-32** filter will become lower if the inductance *Ls'* of **FIG. 32** is appropriately determined through adjustment of the position and size of the recesses 40*a* and 40*b* in the outer conductor extensions 17*a* and 17*b*. The extreme attenuation frequency above this spurious resonance peak P_1 can thus be set at or near the third harmonic $3f_0$ of the fundamental frequency f_0. The third harmonic can be most effectively suppressed in this manner.

In fabricating the **FIGS. 26-32** filter the outer conductor extensions 17*a* and 17*b* with the constricted

necks $41a$ and $41b$ may be formed simultaneously with the outer conductors $5a$ and $5b$ by printing a pasted conductor. Then, if the printed conductor patterns have proved not to provide the desired inductance, the outer conductor extensions $17a$ and $17b$ may be made shorter as by a laser beam or a grinding tool.

Optionally, as indicated by the broken lines in **FIG. 27**, additional holes $43a$ and $43b$ for adjustment of the frequency characteristic may be formed in the first end faces $10a$ and $10b$ of the dielectric bodies $3a$ and $3b$ and parallel to the resonance holes $16a$ and $16b$. For the same purpose, as also indicated by the broken lines in the same figure, recesses $44a$ and $44b$ may be formed in the dielectric bodies $3a$ and $3b$. These holes $43a$ and $43b$ and recesses $44a$ and $44b$ serve to reduce the stray capacitances between resonator coupling conductors $7a$ and $7b$ and terminal conductors $8a$ and $8b$. The reduction of the stray capacitances serve, in turn, to make lower the extreme attenuation frequency f_1 of **FIG. 13** and to make greater the amount of attenuation at that extreme frequency.

Embodiment of FIG. 33

FIG. 33 shows a modification $1g$ of the first dielectric resonator $1f$ of the **FIGS. 26-32** filter, to be combined with another similarly modified resonator, not shown, to make up a wave filter in accordance with the invention. The modified resonator $1g$ features a recess $40a_1$ which is formed in the outer conductor $5a$, instead of in the outer conductor extension $17a$ as in **FIG. 27**. Thus the outer conductor extension $17a$, or its head $42a_1$, is of substantially the same size as the outer conductor first extension $17a$ of the **FIGS. 1-13** filter, and is joined to the outer conductor $5a$ via a neck $41a_1$, although this neck may be considered part of the outer conductor rather than of the extension $17a$.

Thanks to the inductance due to the necks $41a_1$ of this $1g$ and other unshown resonators the **FIG. 33** filter gains the same advantages as the **FIGS. 26-32** filter.

Optionally, as indicated by the broken lines designated 45 in **FIG. 33**, the recess $40a_1$ may be enlarged into the outer conductor extension $17a$ for a higher inductance.

Embodiment of FIG. 34

FIG. 34 shows another modification $1h$ of the first dielectric resonator $1f$ of the **FIGS. 26-32** filter, also to be combined with another similarly modified resonator, not shown, to make up a wave filter in accordance with the invention. The modified resonator lh features a second recess 46 which is formed in the outer conductor $5a$, in addition to the first recess $40a_2$ formed in the outer conductor extension $17a$. Thus the outer conductor extension $17a$ is itself similar to that of the **FIG. 27** resonator $1f$, being comprised of the constricted neck $41a_2$ and head $42a_2$.

As in the **FIGS. 26-32** filter, the peak of spurious resonance can be made to occur at a lower frequency than heretofore by virtue of not only the inductance due to the necks $41a_2$, but also that due to the second recesses 46, of this $1h$ and other unshown resonators.

Embodiment of FIGS. 35 and 36

FIG. 35 shows the second side surface $13a$, and **FIG. 36** the third side surface or bottom $14a$, of still another modification $1i$ of the first dielectric resonator if of the **FIGS. 26-32** filter. This modified resonator $1i$ is also to be combined with another similarly modified resonator, not shown, to make up a wave filter in accordance with the invention.

With reference first to **FIG. 35** it will be noted that that part of the outer conductor extension $17am$, or of its head $42a_3$, which overlies the dielectric body second side surface is wholly separated from the outer conductor $5a$; that is, the recess $40a_3$ extends down to the bottom of the dielectric body. Reference to **FIG. 36** will then reveal that the recess $40a_3$ extends farther beyond the corner between the dielectric body second $13a$ and third $14a$ side surfaces. As another recess 47 is formed on the dielectric body third side surface $14a$, a neck $41a_3$ is left between the recesses $40a_3$ and 47, joining the outer conductor $5a$ to that part of the outer conductor extension head $42a_3$ which overlies the dielectric body third side surface.

As in the **FIGS. 26-32** filter, the peak of spurious resonance can be made to occur at a lower frequency than heretofore by virtue of the inductance due to the necks $41a_3$ of this $1i$ and other unshown resonators.

Embodiment of FIG. 37

The pair of resonators $1j$ and $2j$ shown in **FIG. 37** are modifications of the resonators 1 and 2 of the **FIG. 1-13** filter. The following description of the resonators $1j$ and $2j$ will be best understood from a comparison of **FIGS. 4** and **37**.

The difference of the **FIG. 37** resonators $1j$ and $2j$ from the **FIG. 4** resonators 1 and 2 are:

1. The inner conductor extensions $9a$ and $9b$ of the **FIG. 4** resonators are absent from the **FIG. 37** resonators.
2. The outer conductor second extensions $18a$ and $18b$ of the **FIG. 4** resonators are also absent from the **FIG. 37** resonators.
3. The **FIG. 37** resonators have depressions $50a$ and $50b$ formed in the dielectric body first side surfaces $12a$ and $12b$, in which depressions there are received parts of the resonator coupling condDctors $7a$ and $7b$.

The partial placement of the resonator coupling conductors $7a$ and $7b$ in the dielectric body depressions

50*a* and 50*b* serve to make greater the capacitances between these conductors 7*a* and 7*b* and the inner conductors 4*a* and 4*b*.

There is another advantage arising from the partial placement of the resonator coupling conductors 7*a* and 7*b* in the dielectric body depressions 50*a* and 50*b*. The top surfaces of the conductors 7*a* and 7*b* can be made lower than those of the outer conductors 5*a* and 5*b*, or even those of the dielectric bodies 3*a* and 3*b*. In this manner, when an electromagnetic shield is placed upon the outer conductors 5*a* and 5*b*, the resonator coupling conductors 7*a* and 7*b* are prevented from contacting the shield.

Embodiment of FIG. 38

The pair of resonators 1*k* and 2*k* of **FIG. 38** will also be best understood from a comparison of the first disclosed resonators 1 and 2 as pictured in **FIG. 4**. The differences of the **FIG. 38** resonators 1*k* and 2*k* from the **FIG. 4** resonators 1 and 2 are:

1. The inner conductor extensions 9*a* and 9*b* of the **FIG. 4** resonators 1 and 2 are absent from the **FIG. 38** resonators 1*k* and 2*k*.
2. The outer conductor second extensions 18*a* and 18*b* of the **FIG. 4** resonators 1 and 2 are also absent from the **FIG. 38** resonators 1*k* and 2*k*.
3. The **FIG. 38** resonators 1*k* and 2*k* have resonator coupling conductors 7*a* and 7*b* are disposed in locations different from those of the **FIG. 4** resonators 1 and 2.

The resonator coupling conductors 7*a* and 7*b* overlie the dielectric body second side surface 13*a* and 13*b* and first end surface 10*a* and 10*b* in the **FIG. 38** resonators 1*k* and 2*k*, instead of on the dielectric body first and second side surfaces as in the **FIG. 4** resonators. The absence of the resonator coupling conductors 7*a* and 7*b* from the dielectric body first side surfaces 12*a* and 12*b* serve to prevent their contact with the electromagnetic shield placed on the outer conductors 5*a* and 5*b*.

Embodiment of FIG. 39

The pair of resonators 1*l* and 2*l* shown in **FIG. 39** differ from the resonators 1 and 2 of the **FIGS. 1-13** filter in:

1. The absence of the inner conductor extensions 9*a* and 9*b*.
2. The absence of the outer conductor second extensions 18*a* and 18*b*.
3. The shape of the dielectric bodies 3*a* and 3*b*.

The shape of the dielectric bodies 3*a* and 3*b* of the **FIG. 39** filter differ from that of the **FIGS. 1-13** dielectric bodies in that all the longitudinal edges of the **FIG. 39** bodies 3*a* and 3*b* are rounded with a predetermined radius. The resonator coupling conductors 7*a* and 7*b*, terminal conductors 8*a* and 8*b*, and outer conductor extensions 17*a* and 17*b* are all formed on the two neighboring side surfaces of each dielectric body across the rounded edge therebetween.

The rounded longitudinal edges of the dielectric bodies 3*a* and 3*b* can be utilized advantageously in coupling together the two resonators 1*l* and 2*l* and mounting them on the circuit board 25 as in **FIG. 39**. Since the rounded edges provide a gap therebetween when the resonators 1*l* and 2*l* are placed side by side, an electroconductive bonding agent such as solder can be filled in this gap, as indicated at 24, for coupling them together. In mounting the resonators on the circuit board 25, the bonding agent can be filled at 29 in the space created by the two contiguous rounded edges between the outer conductor extensions 17*a* and 17*b* and the grounding conductor 26 on the circuit board 25. The terminal conductors 8*a* and 8*b* can likewise be joined at 29 to the terminal conductors 27 and 28 on the circuit board 25. Not only can the resonators 1*l* and 2*l* be positively coupled to each other and to the circuit board 25, but also it is visually observable whether they are or not.

The edges of the dielectric bodies may therefore be rounded with any radius that is considered optimum for firm coupling of the resonators to each other and to the circuit board. It is even possible to form the dielectric bodies into cylindrical shape.

Embodiment of FIGS. 40-42

The pair of resonators 1*m* and 2*m* shown in **FIGS. 40-42** differ from the resonators 1 and 2 of the **FIGS. 1-13** filter in:

1. The position of the resonator coupling conductors 7*a* and 7*b*.
2. The absence of the inner conductor extensions.
3. The absence of the outer conductor second extensions 18*a* and 18*b*.
4. The shape and size of the remaining outer conductor extensions 17*a*' and 17*b*'.

The resonator coupling conductors 7*a* and 7*b* of the **FIGS. 40-42** resonators 1*m* and 2*m* are disposed centrally of the second side surfaces 13*a* and 13*b* of the dielectric bodies 3*a* and 3*b*. That part of the outer conductors 5*a* and 5*b* which overlie the dielectric body second side surfaces 13*a* and 13*b* have windows created therein for loosely receiving the resonator coupling conductors 7*a* and 7*b*.

The remaining outer conductor extensions 17*a*' and 17*b*' are much larger in size than the outer conductor first extensions 17*a* and 17*b* of the **FIGS. 4** resonators 1 and 2. The extensions 17*a*' and 17*b*' cover all of the dielectric body first 12*a* and 12*b* and second 13*a* and

13*b* side surfaces and parts of the dielectric body third 14*a* and 14*b* and fourth 15*a* and 15*b* side surfaces. The terminal conductors 8*a* and 8*b* are the same in shape, size and position with those of the **FIG. 4** resonators 1 and 2.

Thus the outer conductor extensions 17*a'* and 17*b'* contribute toward greater isolation of the terminal conductors 8*a* and 8*b* from each other and also provide the capacitances Ct_1' and Ct_2', **FIG. 32**, for the wavelength shortening effect. The resonator coupling conductors 7*a* and 7*b* of this embodiment also provide the capacitances C_2 and C_3 of both **FIGS. 12** and **32** circuits.

Embodiment of FIGS. 43 and 44

The pair of dielectric resonators 1*n* and 2*n* of the **FIGS. 43** and **44** filter are similar in construction to the resonators 1*m* and 2*m* of the **FIGS. 40-42** filter. The only difference between these filters is that the resonator 2*n* of the **FIGS. 43** and **44** filter is opposite in orientation to the corresponding resonator 2*m* of the **FIGS. 40-42** filter.

With the resonators 1*n* and 2*n* so oriented in opposite directions, the terminal conductors 8*a* and 8*b* are spaced a greater distance from each other than when the resonators are oriented as in **FIGS. 40-42**. This positional advantage coacts with the outer conductor extensions 17*a'* and 17*b'*, as well as with the outer conductors 5*a* and 5*b*, to afford still greater isolation between the terminal conductors 8*a* and 8*b*.

Possible Modifications

Notwithstanding the foregoing detailed disclosure it is not desired that the present invention be limited by the exact showing of the drawings or the description thereof. A variety of modifications and alterations are considered possible in the practice of this invention in order to conform to design preferences or to the requirements of each specific application. The following is but a few of such possible modifications:

1. Not only two or three dielectric resonators, as disclosed herein, but four or more could be juxtaposed for constituting wave filters in accordance with the invention.
2. The larger diameter portions 33*a* and 33*b* of the resonance holes of the **FIGS. 21-23** dielectric resonators 1*e* and 2*e* could be square or otherwise polygonal in cross sectional shape.
3. The larger diameter portions 33*a* and 33*b* of the resonance holes of the **FIGS. 21-23** resonators 1*e* and 2*e* could be made so shallow (e.g., somewhat more than the thickness of the inner conductors 4*a* and 4*b*) that the inner conductor portions 35*a* and 35*b* lining the larger diameter portions would perform the same functions as the inner conductor extensions 9*a* and 9*b* of the **FIGS. 1-13** filter.

Claims

1. A dielectric wave filter having at least two dielectric resonators (1 and 2 with or without 30) in juxtaposition, wherein each dielectric resonator comprises a dielectric body (3*a* or 3*b*) having a pair of opposite end surfaces (10*a* and 11*a*, or 10*b* and 11*b*), a plurality of side surfaces (12*a*, 13*a*, 14*a* and 15*a*; or 12*b*, 13*b*, 14*b* and 15*b*) between the pair of end surfaces, and a resonance hole (16*a* or 16*b*) extending between the pair of end surfaces, one (13*a* or 13*b*) of the side surfaces of each dielectric body confronting the other dielectric body, an inner conductor (4*a* or 4*b*) covering an inner surface of the dielectric body, an outer conductor (5*a* or 5*b*) covering those parts of the side surfaces of the dielectric body which are contiguous to one (11*a* or 11*b*) of the end surfaces of the dielectric body, the outer conductors on both dielectric bodies being joined (at 23) to each other both mechanically and electrically, a shorting conductor (6*a* or 6*b*) covering said one end surface (11*a* or 11*b*) of the dielectric body and electrically interconnecting the inner and the outer conductors, and a resonator coupling conductor (7*a* or 7*b*) covering part of at least that side surface (13*a* or 13*b*) of each dielectric body which confronts the other dielectric body, the resonator coupling conductors on both dielectric bodies being joined (at 24) to each other both mechanically and electrically, characterized in that a terminal conductor (8*a* or 8*b*) covers part of the side surfaces of each dielectric body and disposed adjacent the other (10*a* or 10*b*) of the end surfaces thereof, the terminal conductors on both dielectric bodies being disposed at least on those side surfaces (15*a* and 15*b*) of the dielectric bodies which face away from each other, and that an outer conductor extension (17*a* or 17*b*) extends from the outer conductor (5*a* or 5*b*) on each dielectric body toward said other end surface (10*a* or 10*b*) thereof, the outer conductor extensions on both dielectric bodies being disposed at least on those side surfaces (13*a* and 13*b*) of the dielectric bodies which confront each other, thereby intervening between the terminal conductors (8*a* and 8*b*) on both dielectric bodies for electrically isolating the terminal conductors from each other.

2. A dielectric wave filter as claimed in claim 1, wherein the side surfaces of each dielectric body (3*a* or 3*b*) include a first side surface (12*a* or 12*b*), a second side surface (13*a* or 13*b*) contiguous to the first side surface and confronting the other dielectric body, a third side surface (14*a* or 14*b*) contiguous to the second side surface, and a fourth side surface (15*a* or 15*b*) contiguous to both first and third side surfaces and facing away from the other dielectric body, characterized in that the resonator coupling conductor (7*a* or 7*b*) on each dielectric body covers

part of the first side surface (12*a* or 12*b)* thereof in addition to part of the second side surface (13*a* or 13*b*) thereof.

3. A dielectric wave filter as claimed in claim 2, characterized in that the outer conductor extension (17*a* or 17*b*) on each dielectric body covers parts of the second (13*a* or 13*b*) and third (14*a* or 14*b*) side surfaces thereof.

4. A dielectric wave filter as claimed in claim 3, characterized in that the terminal conductor (8*a* or 8*b*) on each dielectric body covers parts of the third (14*a* or 14*b)* and fourth (15*a* or 15*b)* side surfaces thereof.

5. A dielectric wave filter as claimed in claim 1, characterized in that each dielectric resonator (1 or 2) further comprises a second outer conductor extension (18*a* or 18*b*) extending from the outer conductor (5*a* or 5*b*) on each dielectric body toward said other end surface (10*a* or 10*b*) thereof.

6. A dielectric wave filter as claimed in claim 5, wherein the side surfaces of each dielectric body (3*a* or 3*b)* include a first side surface (12*a* or 12*b*), a second side surface (13*a* or 13*b)* contiguous to the first side surface and confronting the other dielectric body, a third side surface (14*a* or 14*b*) contiguous to the second side surface, and a fourth side surface (15*a* or 15*b)* contiguous to both first and third side surfaces and facing away from the other dielectric body, characterized in that the second outer conductor extension (18*a* or 18*b*) on each dielectric body covers parts of the first (12*a* or 12*b*) and fourth (15*a* or 15*b*) side surfaces thereof.

7. A dielectric wave filter as claimed in claim 6, characterized in that the terminal conductor (8*a* or 8*b)* on each dielectric body covers parts of the third (14*a* or 14*b)* and fourth (15*a* or 15*b*) side surfaces thereof.

8. A dielectric wave filter as claimed in claim 7, characterized in that each dielectric resonator (1 or 2) further comprises an inner conductor extension (9*a* or 9*b*) disposed on said other end surface (10*a* or 10*b*) of each dielectric body and joined to the inner conductor (4*a* or 4*b*) thereof.

9. A dielectric wave filter as claimed in claim 8, characterized in that the inner conductor extension (9*a* or 9*b*) is so patterned on said other end surface (10*a* or 10*b)* of each dielectric body that capacitance between the inner conductor extension and the resonator coupling conductor (7*a* or 7*b)* is less than capacitance between the inner conductor extension and each outer conductor extension (17*a* or 17*b*), and that capacitance between the inner conductor extension and the terminal conductor (8*a* or 8*b)* is less than capacitance between the inner conductor extension and each outer conductor extension.

10. A dielectric wave filter as claimed in claim 8, characterized in that the inner conductor extension (9*a* or 9*b*) on said other end surface of each dielectric body is symmetrical in shape with respect to a line connecting a corner between the first (12*a* or 12*b*) and the second (13*a* or 13*b*) side surface of the dielectric body and a corner between the third (14*a* or 14*b*) and the fourth (15*a* or 15*b*) side surface of the dielectric body.

11. A dielectric wave filter as claimed in claim 8, characterized in that the inner conductor extension (9*a* or 9*b*) on said other end surface (10*a* or 10*b*) of each dielectric body comprises a first portion extending from the resonance hole (16*a* or 16*b*) toward a corner between the second (13*a* or 13*b)* and the third (14*a* or 14*b*) side surface of the dielectric body, and a second portion extending from the resonance hole toward a corner between the first (12*a* or 12*b*) and the fourth (15*a* or 15*b*) side surface of the dielectric body.

12. A dielectric wave filter as claimed claim 11, characterized in that the first and the second portion of each inner conductor extension (9*a* or 9*b*) are each rectangular in shape.

13. A dielectric wave filter as claimed in claim 12, characterized in that each of the first and the second portion of each inner conductor extension ($9a_1$) is formed to include a plurality of teeth (31) along their edges..

14. A dielectric wave filter as claimed in claim 11,characterized in that each of the first and the second portion of each inner conductor extension ($9a_2$) is in the shape of a strip bent right-angularly at a plurality of points thereon.

15. A dielectric wave filter as claimed in claim 11, characterized in that the first and the second portion of each inner conductor extension ($9a_3$) are each circular in shape.

16. A dielectric wave filter as claimed in claim 11, characterized in that the first and the second portion of each inner conductor extension ($9a_4$) are each in the shape of a band having a tapering end.

17. A dielectric wave filter as claimed in claim 11, characterized in that the first and the second portion of each inner conductor extension ($9a_5$) are in combination elliptic in shape.

18. A dielectric wave filter as claimed in claim 1, characterized in that the resonance hole (16*a* or 16*b*) in each dielectric body comprises a smaller diameter portion (32*a* or 32*b*) adjacent said one end surface (11*a* or 11*b*) of the dielectric body, and a larger diameter portion (33*a* or 33*b*) adjacent said other end surface (10*a* or 10*b*) of the dielectric body.

19. A dielectric wave filter as claimed in claim 1, characterized in that the inner conductor (4*a* or 4*b*), outer conductor (5*a* or 5*b*), shorting conductor (6*a* or 6*b*), resonator coupling conductor (7*a* or 7*b*), terminal conductor (8*a* or 8*b*), and outer conductor extension (17*a* or 17*b*) on each dielectric body are each a lamination of layers (36 and 37) of different electroconductive materials.

20. A dielectric wave filter as claimed in claim 1, characterized in that the outer conductor extension (17*a* or 17*b*) on each dielectric body is formed to include a constricted neck portion (41*a* or 41*b*) and a head portion (42*a* or 42*b*).

21. A dielectric wave filter as claimed in claim 1, wherein the side surfaces of each dielectric body include a first side surface (12*a* or 12*b*), a second side surface (13*a* or 13*b*) contiguous to the first side surface and confronting the other dielectric body, a third side surface (14*a* or 14*b*) contiguous to the second side surface, and a fourth side surface (15*a* or 15*b*) contiguous to both first and third side surfaces and facing away from the other dielectric body, characterized in that each resonator coupling conductor (7*a* or 7*b*) covers parts of the first and the second side surface of each dielectric body, and that each resonator coupling conductor is partly received in a depression (50*a* or 50*b*) formed in the first side surface.

22. A dielectric wave filter as claimed in claim 1, characterized in that the resonator coupling conductor (7*a* or 7*b*) additionally covers part of said other end surface (10*a* or 10*b*) of each dielectric body.

23. A dielectric wave filter as claimed in claim 1, characterized in that each dielectric body has rounded corners between the side surfaces.

24. A dielectric wave filter as claimed in claim 1, characterized in that the resonator coupling conductor (7*a* or 7*b*) on each dielectric body is disposed approximately centrally of one side surface (13 *a* or 13*b*) of the dielectric body which confronts the other dielectric body.

25. A dielectric wave filter as claimed in claim 24, characterized in that the dielectric resonators (1 and 2) are of like construction and oriented in opposite directions.

FIG. 1

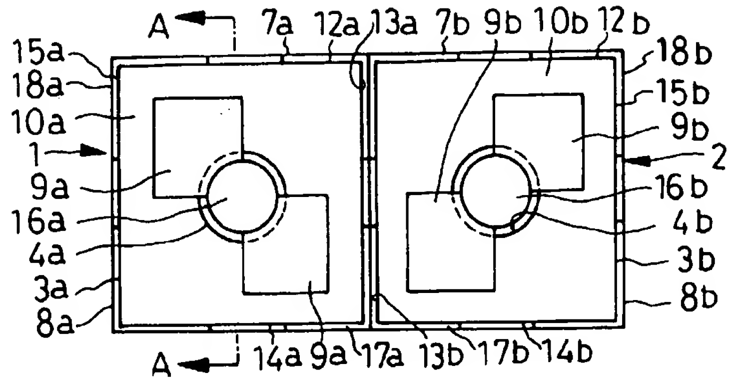


FIG. 2

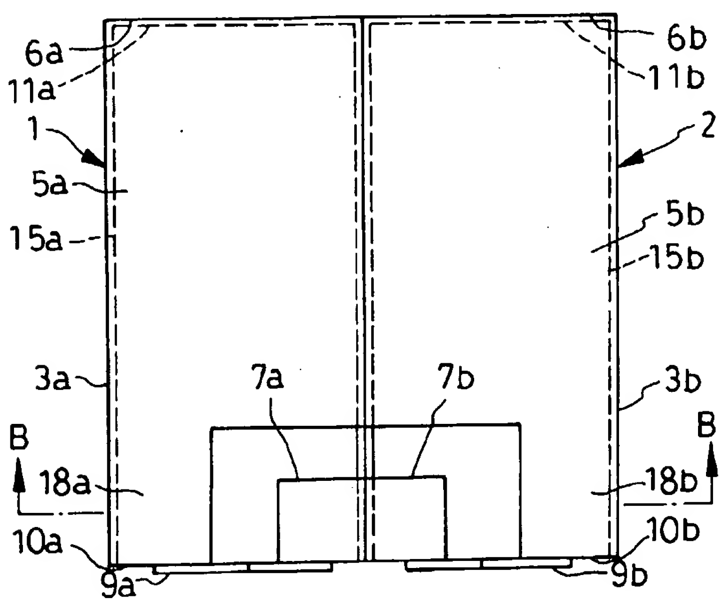


FIG. 3

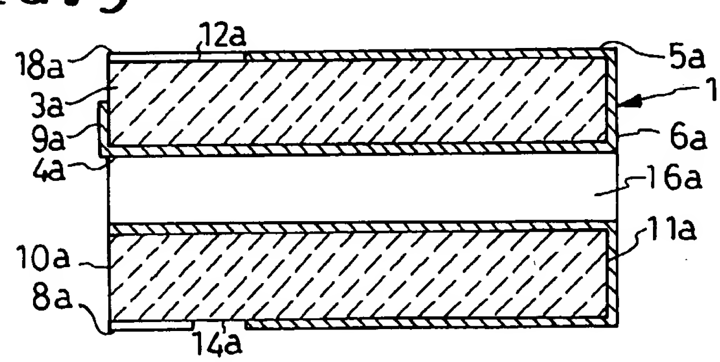


FIG. 4

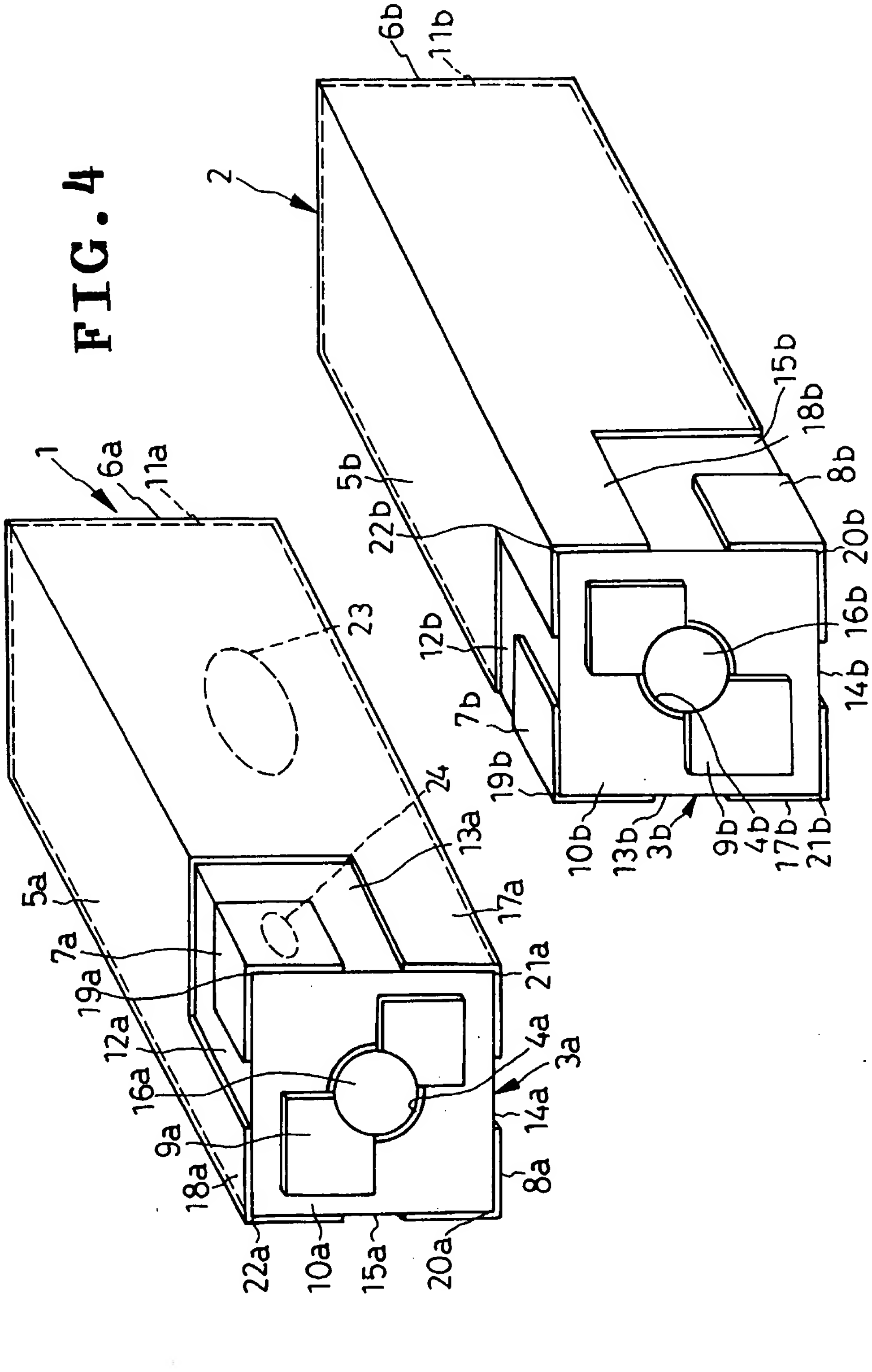

1
2
5a
6a
11a
23
24
13a
17a
7a
19a
21a
12a
16a
4a
3a
9a
14a
18a
8a
22a
10a
15a
20a
6b
11b
15b
18b
5b
8b
22b
20b
12b
16b
7b
14b
19b
10b
13b
3b
9b
4b
17b
21b

FIG.5

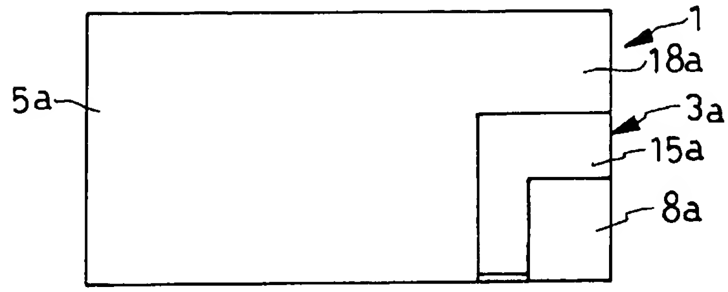


FIG.6

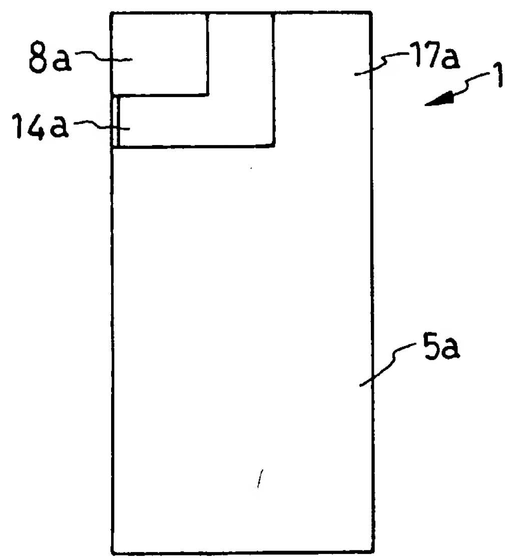


FIG.7

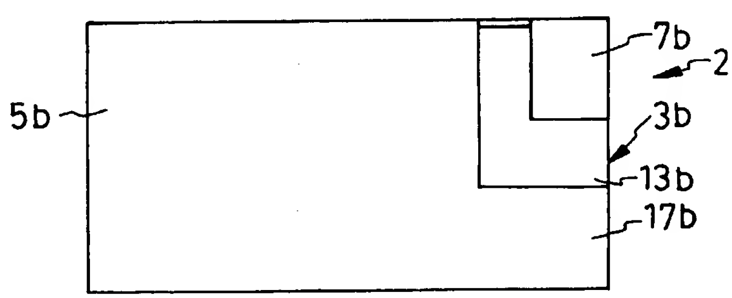


FIG.8

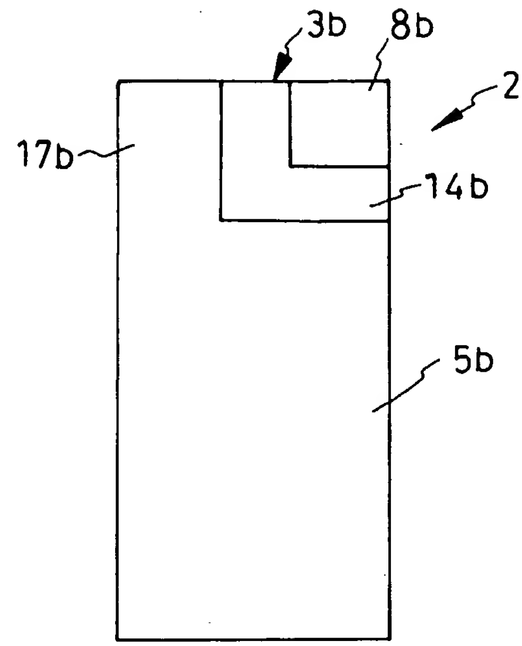


FIG.9

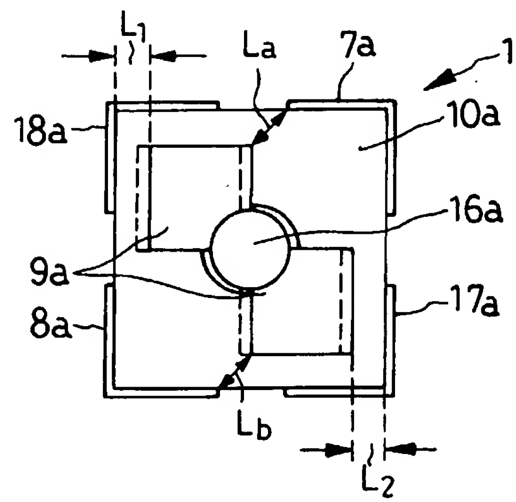


FIG. 10

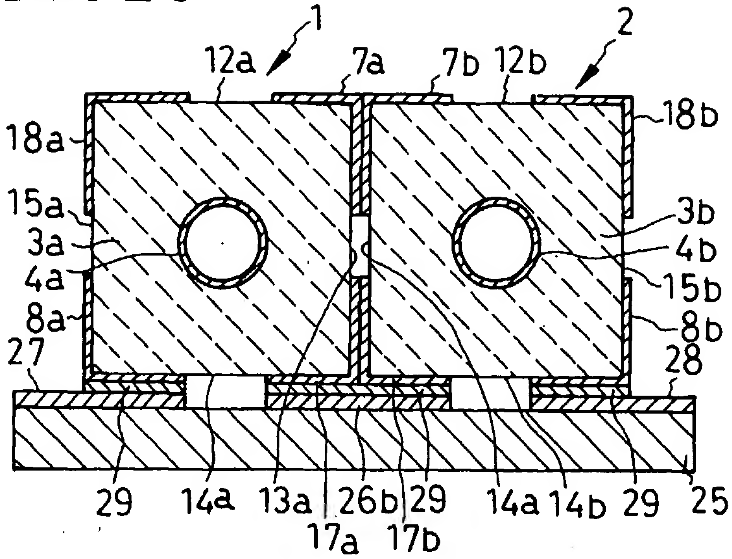

1
2
12a
7a
7b
12b
18a
18b
15a
3a
4a
8a
27
3b
4b
15b
8b
28
29
14a
13a
26b
29
14a
14b
29
25
17a
17b

FIG. 11

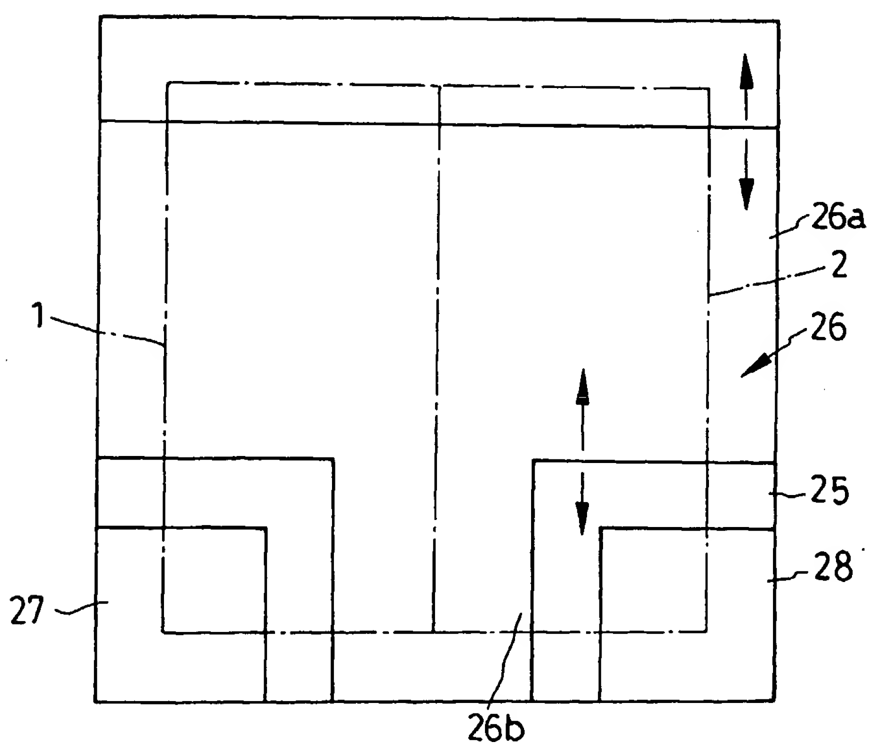

26a
2
1
26
25
28
27
26b

FIG.12

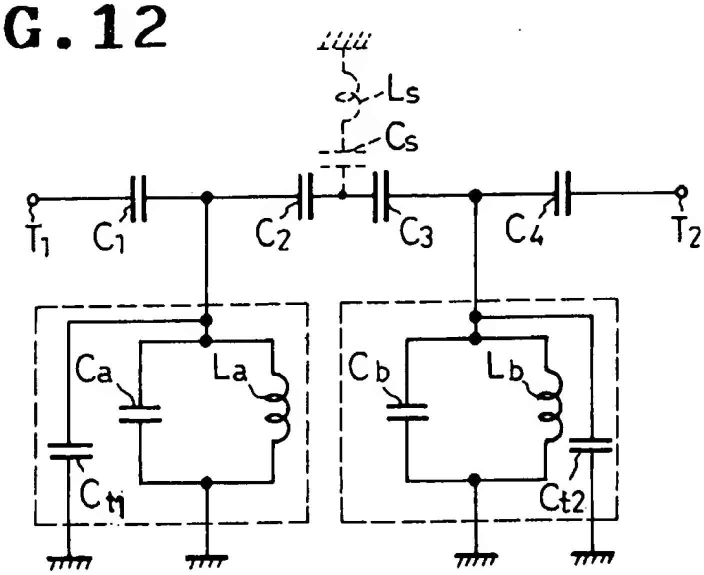

Ls
Cs
T1
C1
C2
C3
C4
T2
Ca
La
Cb
Lb
Ct1
Ct2

FIG.13

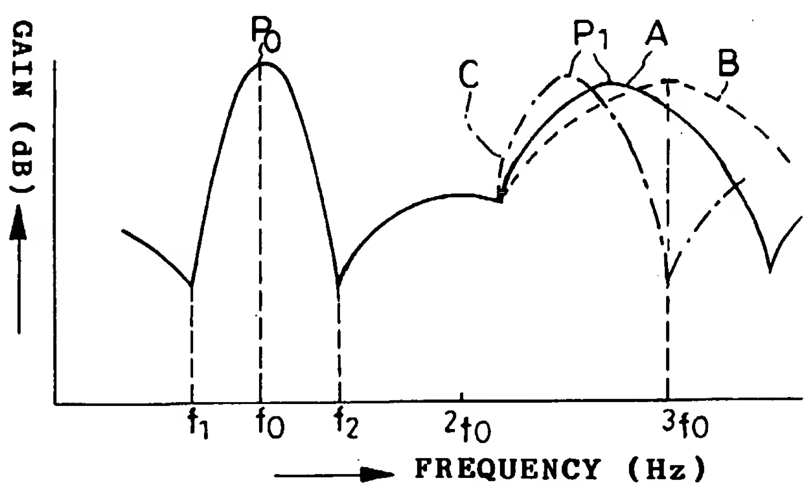

GAIN (dB)
P0
C
P1
A
B
f1
f0
f2
2f0
3f0
FREQUENCY (Hz)

FIG.14

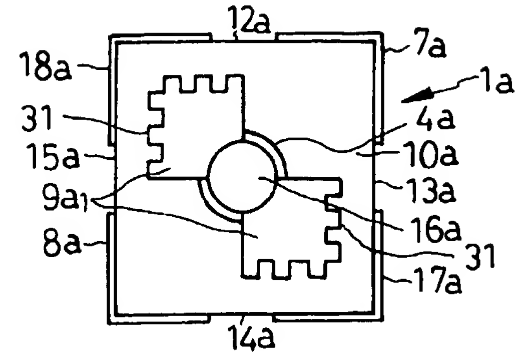


FIG.15

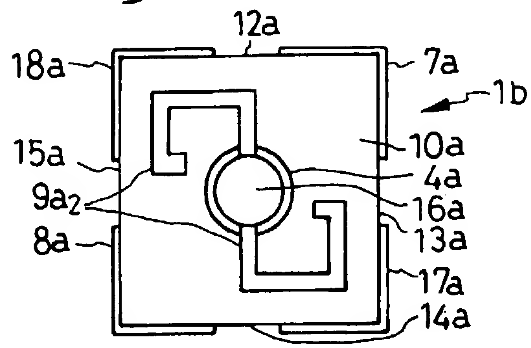


FIG.16

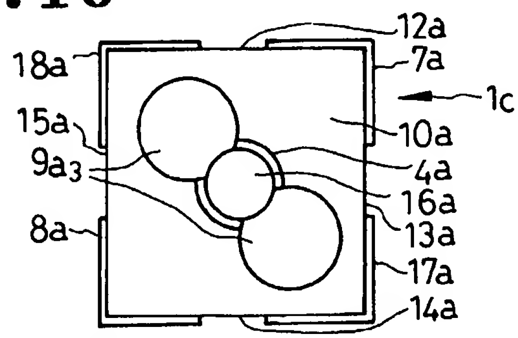


FIG.17

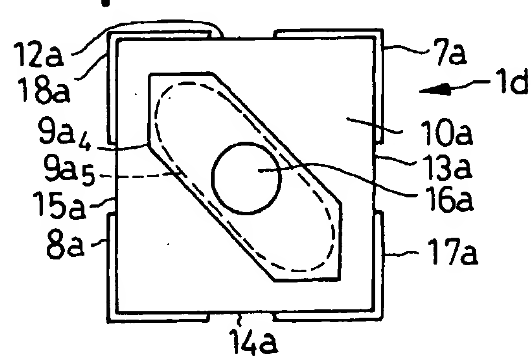


FIG.18

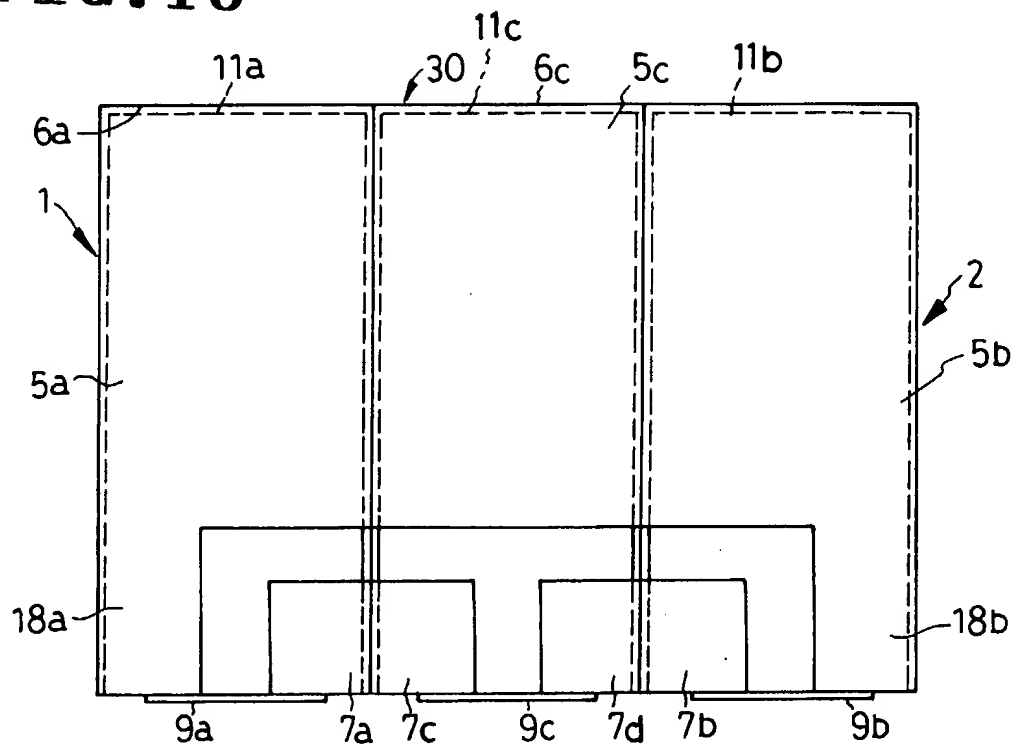
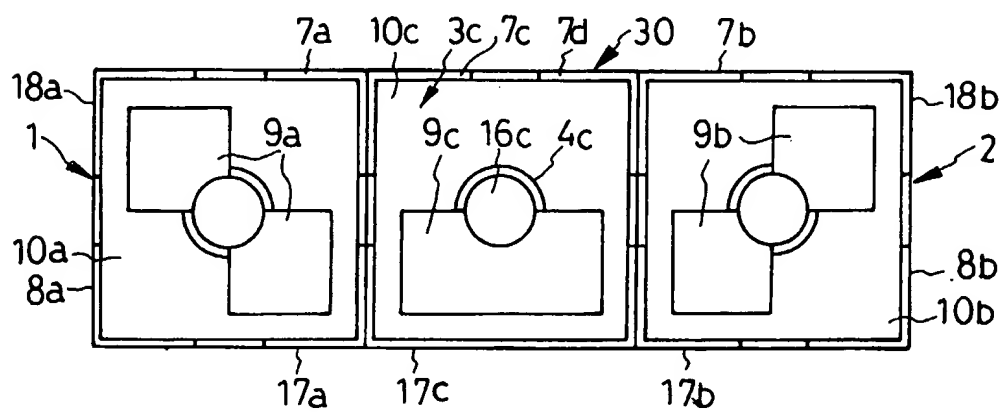

11c
11a
30
6c
5c
11b
6a
1
2
5b
5a
18a
18b
9a
7a
7c
9c
7d
7b
9b

FIG.19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3c
7c
7d
30
7b
18a
18b
9a
9c
16c
4c
9b
1
2
10a
8a
8b
10b
17a
17c
17b

FIG.20

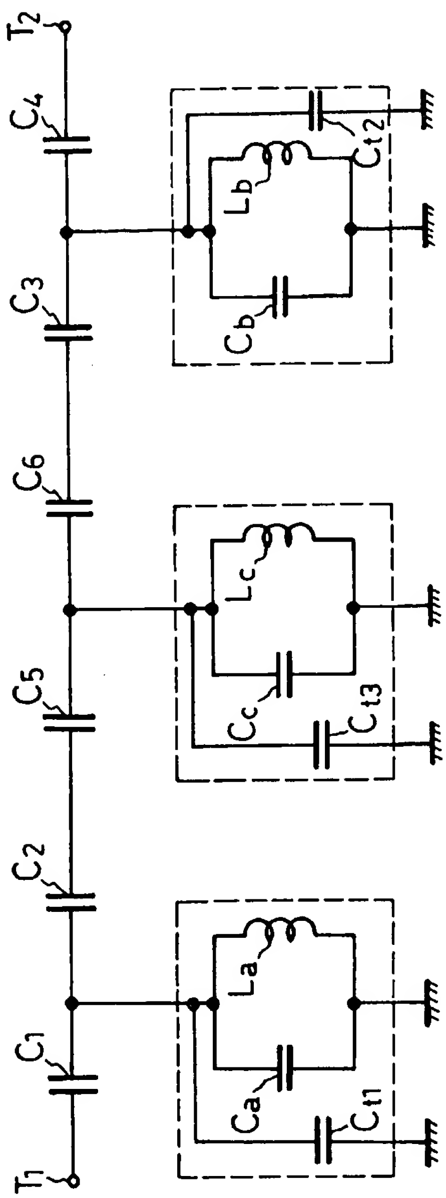
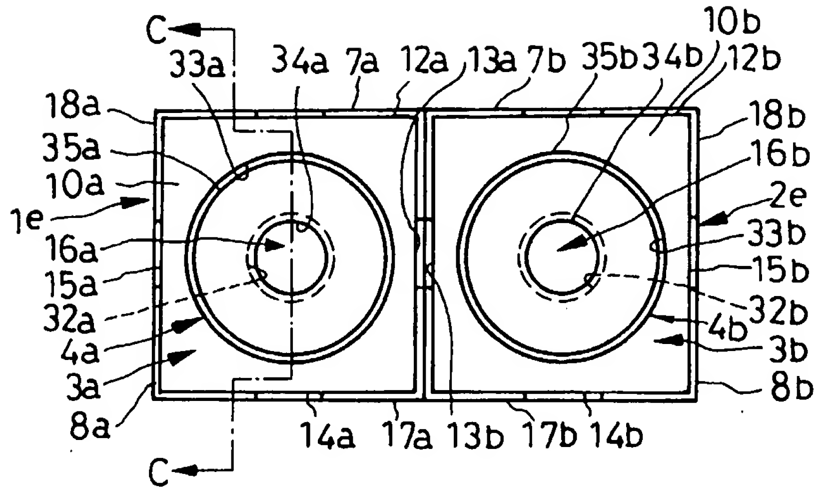


FIG.21


C
33a
34a
7a
12a
13a
7b
35b
34b
10b
12b
18a
35a
10a
1e
16a
15a
32a
4a
3a
8a
18b
16b
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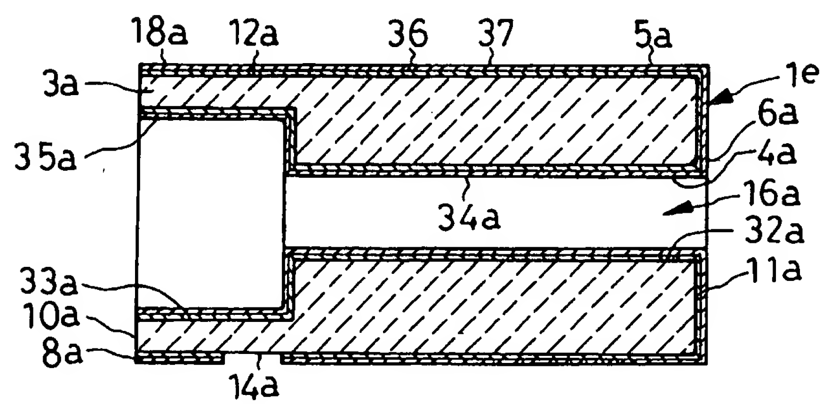
32b
4b
3b
8b
14a
17a
13b
17b
14b
C

FIG.22


18a
12a
36
37
5a
3a
1e
6a
35a
4a
16a
34a
32a
33a
11a
10a
8a
14a

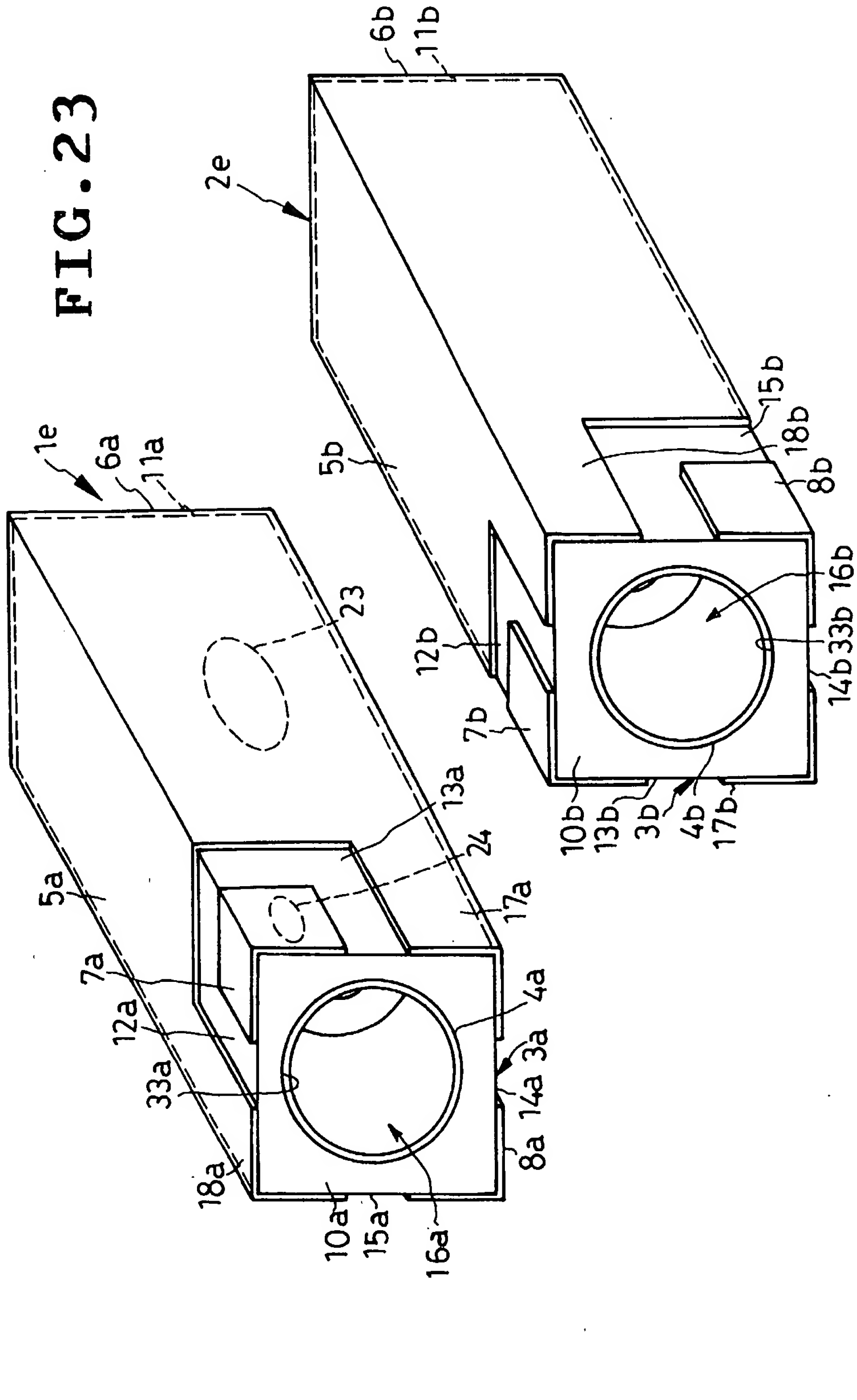

1e
6a
11a
5a
23
13a
24
17a
7a
12a
33a
18a
10a
15a
16a
4a
3a
14a
8a
2e
6b
11b
5b
15b
18b
8b
12b
16b
33b
14b
7b
10b
13b
3b
4b
17b

FIG.23

FIG.24

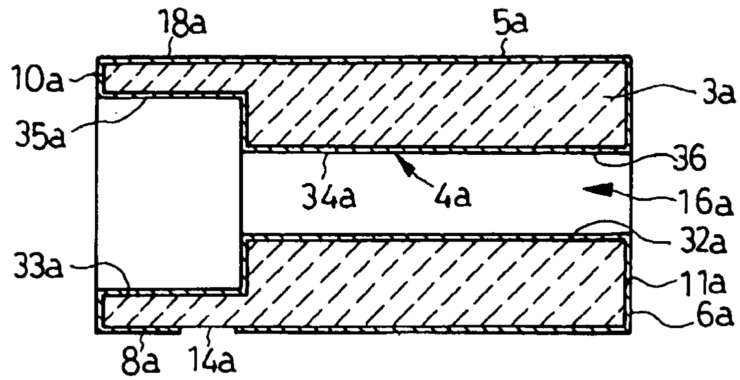


FIG.25

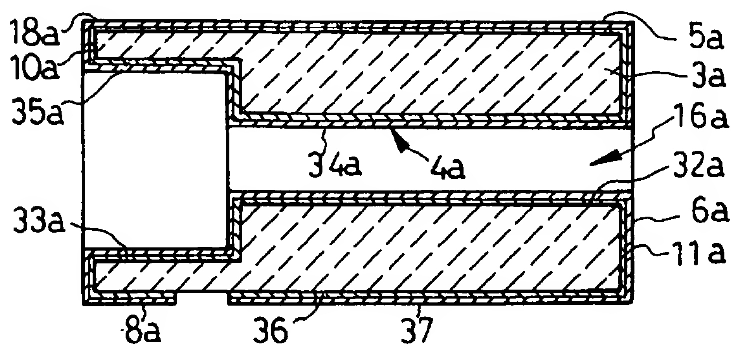


FIG.26

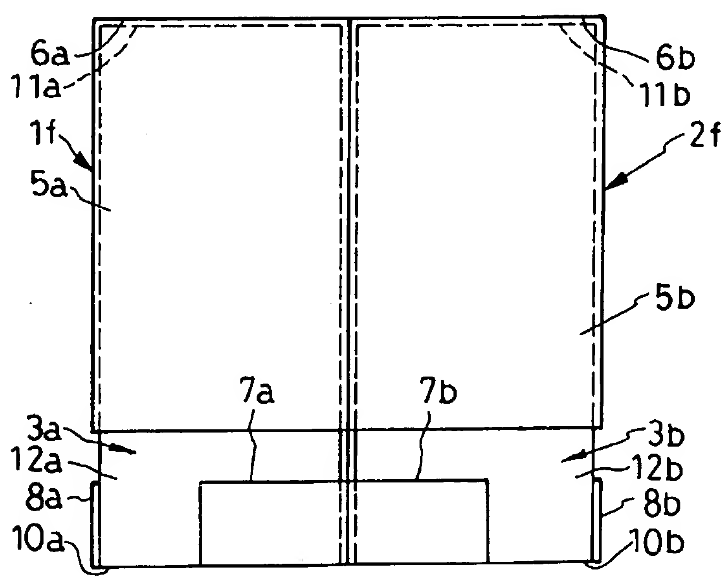


FIG. 27

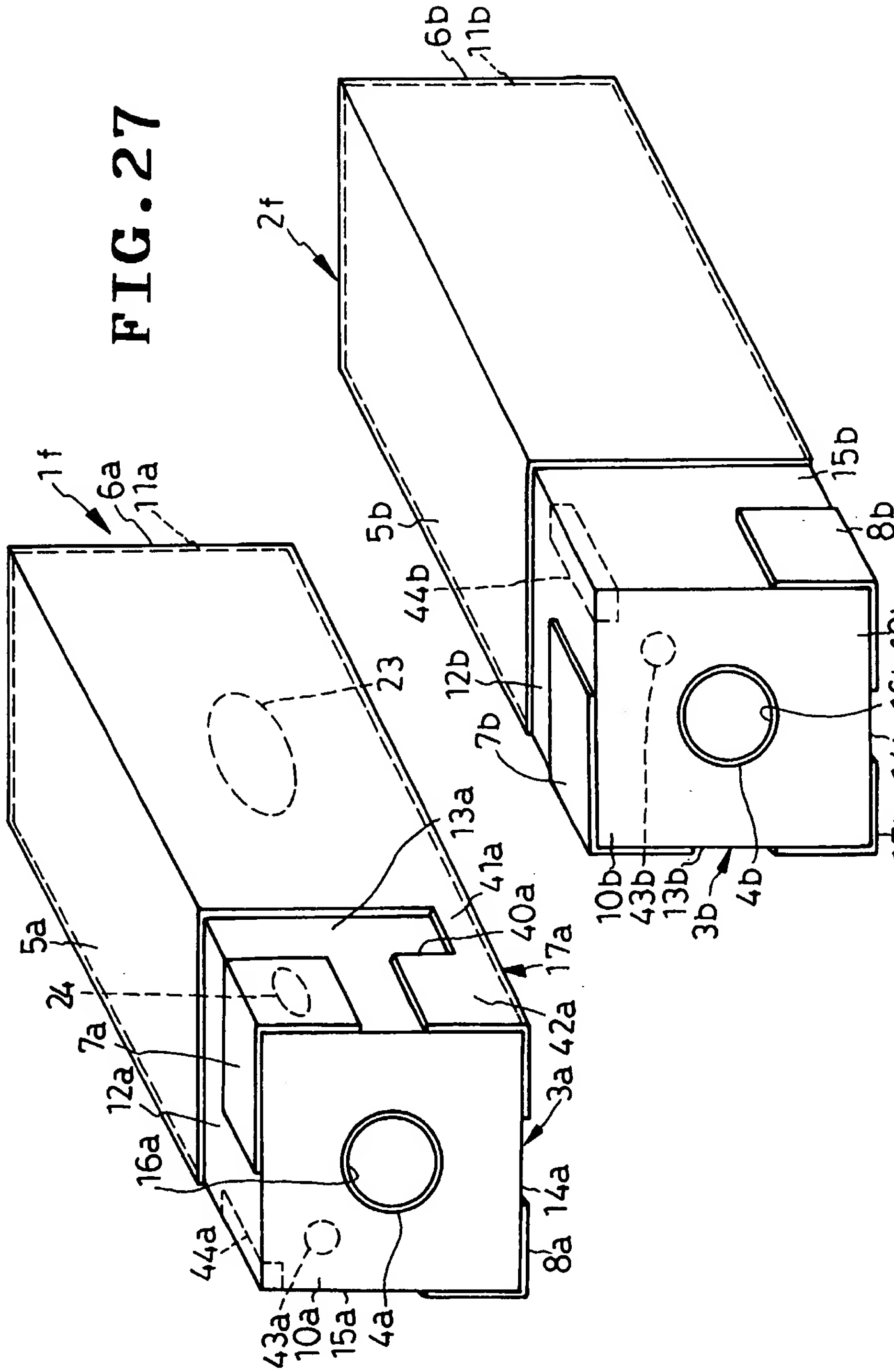

1f
6a
11a
5a
24
7a
12a
16a
44a
43a
10a
15a
4a
8a
14a
3a
42a
17a
40a
41a
13a
23
2f
6b
11b
5b
44b
12b
7b
10b
43b
13b
3b
4b
17b
14b
16b
10b
8b
15b

FIG.28

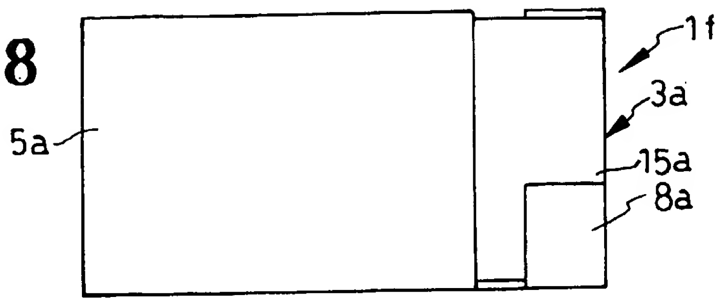


FIG.29

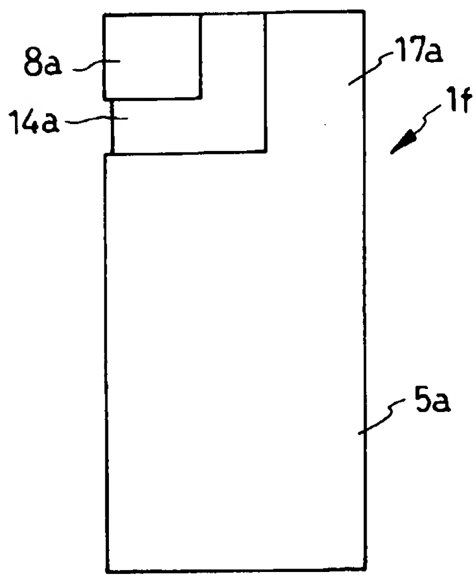


FIG.30

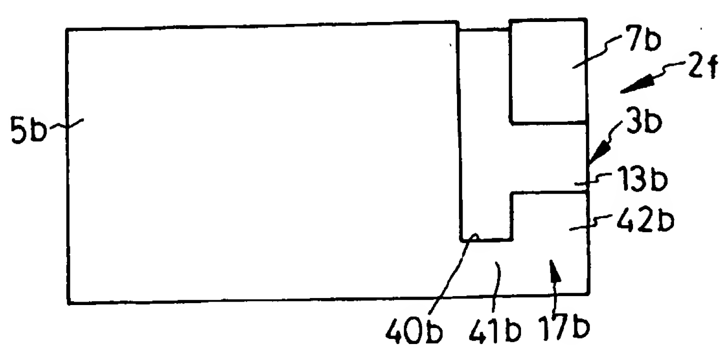


FIG. 31

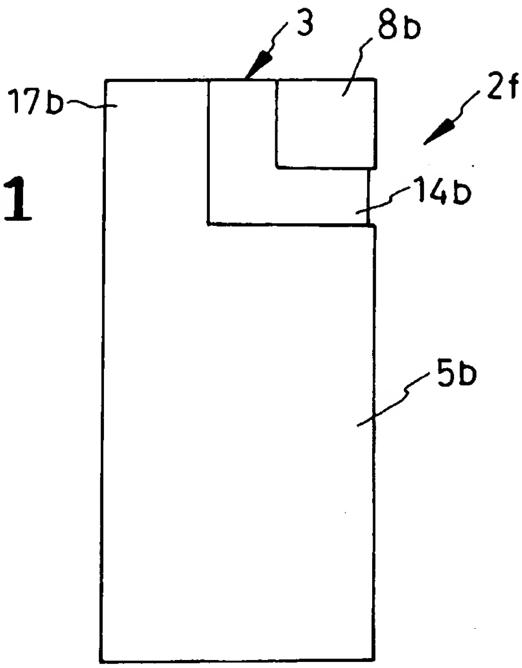


FIG. 32

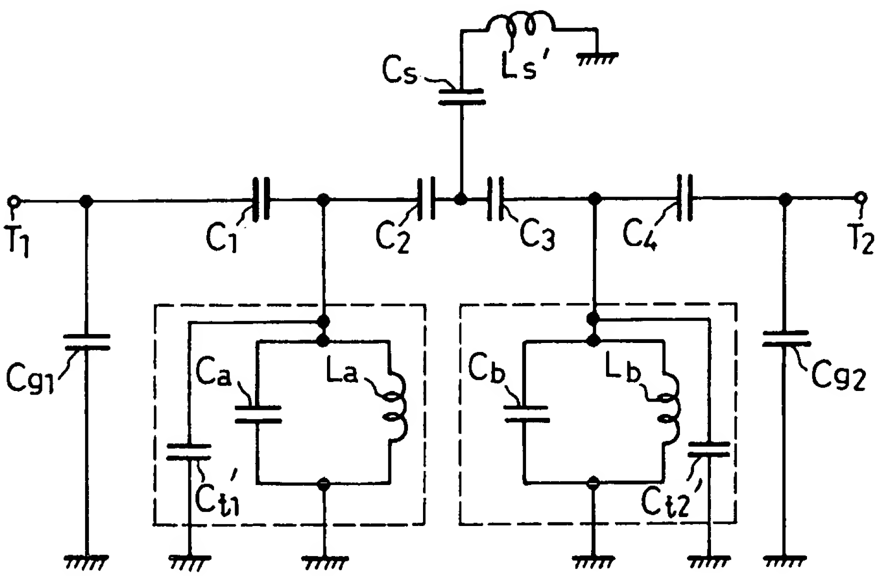


FIG. 33

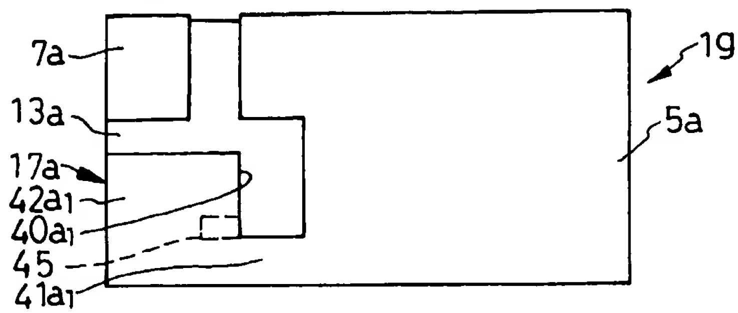


FIG. 34

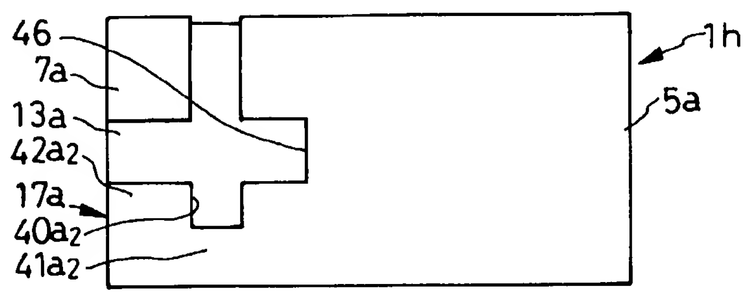


FIG. 35

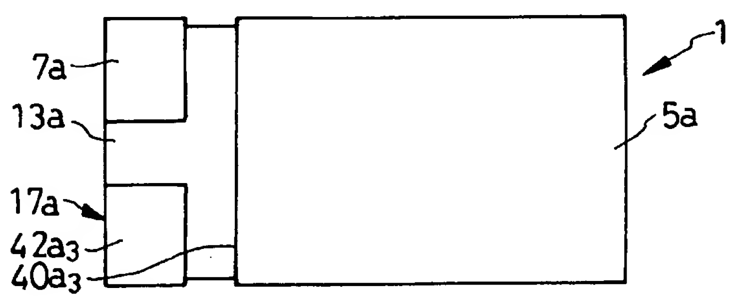
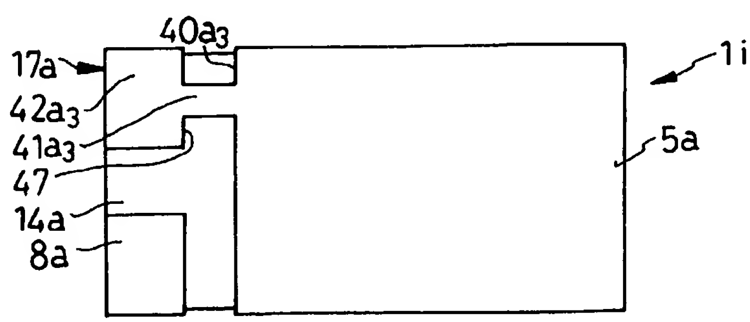


FIG. 36



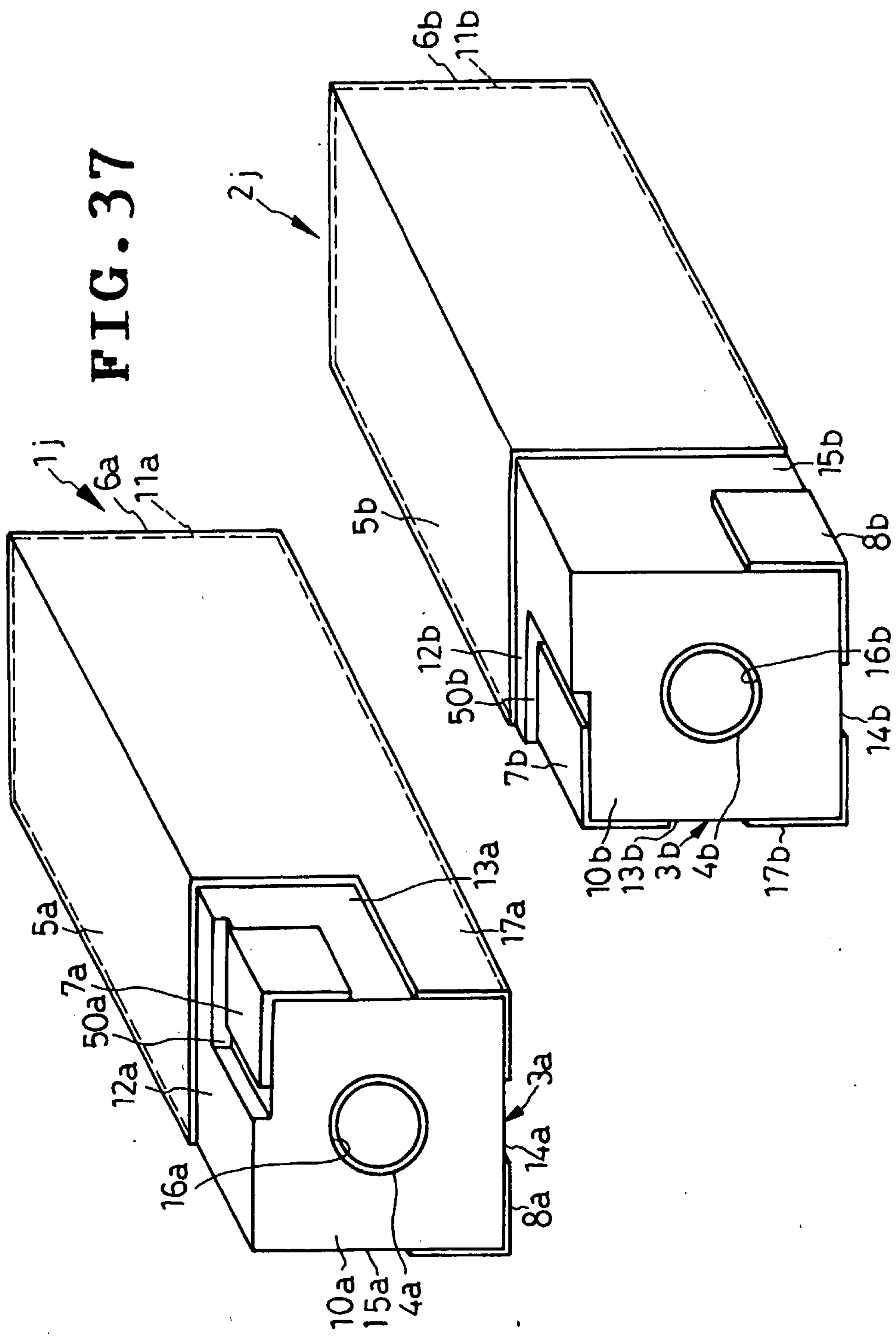
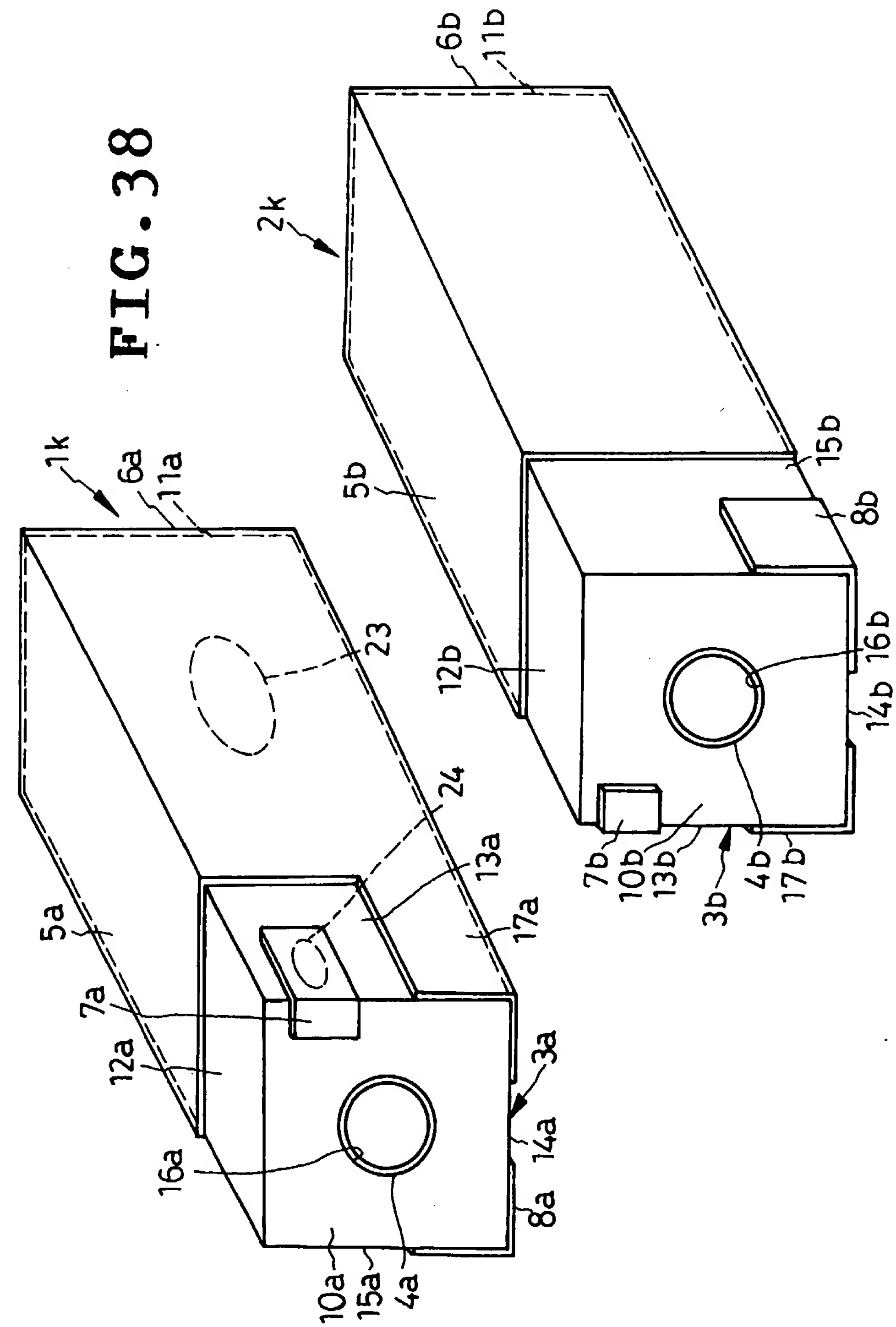

1j
6a
11a
5a
7a
50a
12a
16a
10a
15a
4a
8a
14a
3a
17a
13a
2j
6b
11b
5b
12b
50b
7b
10b
13b
3b
4b
17b
14b
16b
8b
15b

FIG. 37



1k
6a
11a
23
24
13a
17a
5a
7a
12a
3a
14a
16a
8a
10a
15a
4a
2k
6b
11b
5b
15b
8b
12b
16b
14b
7b
10b
13b
3b
4b
17b

FIG.38

FIG. 39

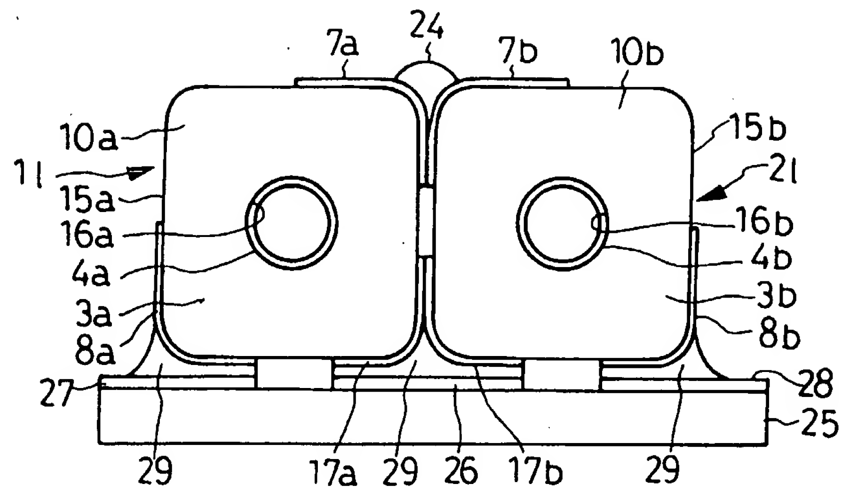

24
7a
7b
10b
10a
15b
11
21
15a
16b
16a
4b
4a
3b
3a
8b
8a
28
27
25
29
17a
29
26
17b
29

FIG. 43

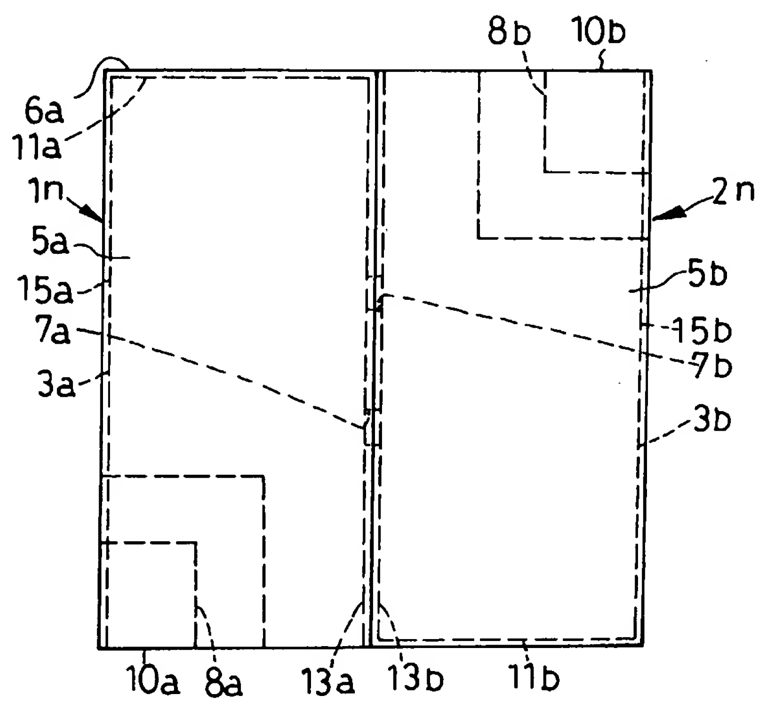

8b
10b
6a
11a
1n
2n
5a
5b
15a
15b
7a
7b
3a
3b
10a
8a
13a
13b
11b

FIG.40

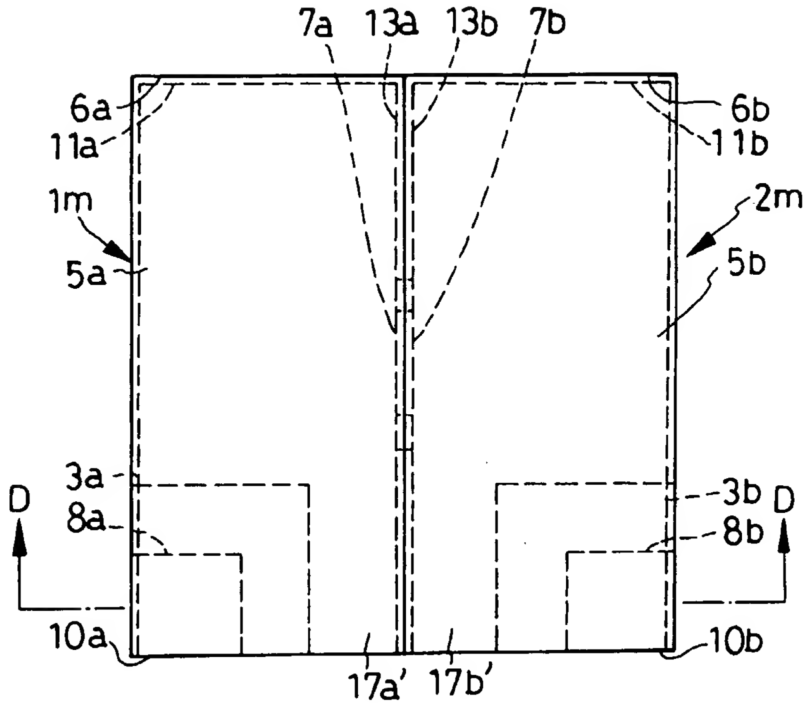
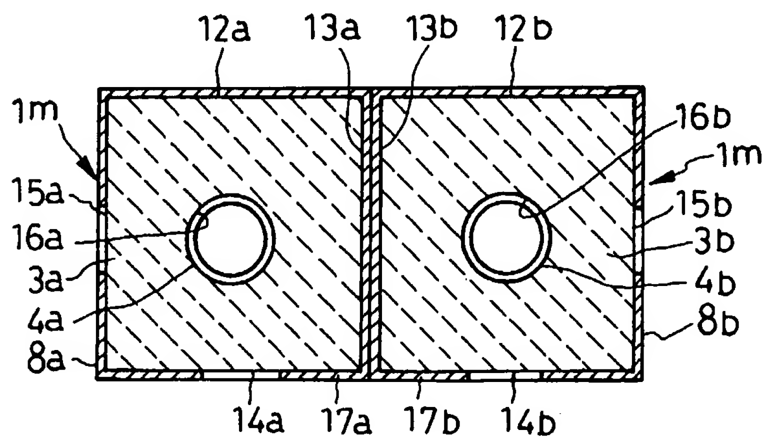

7a
13a
13b
7b
6a
11a
1m
5a
6b
11b
2m
5b
3a
8a
D
10a
3b
8b
D
10b
17a'
17b'

FIG.41


12a
13a
13b
12b
1m
15a
16a
3a
4a
8a
16b
1m
15b
3b
4b
8b
14a
17a
17b
14b

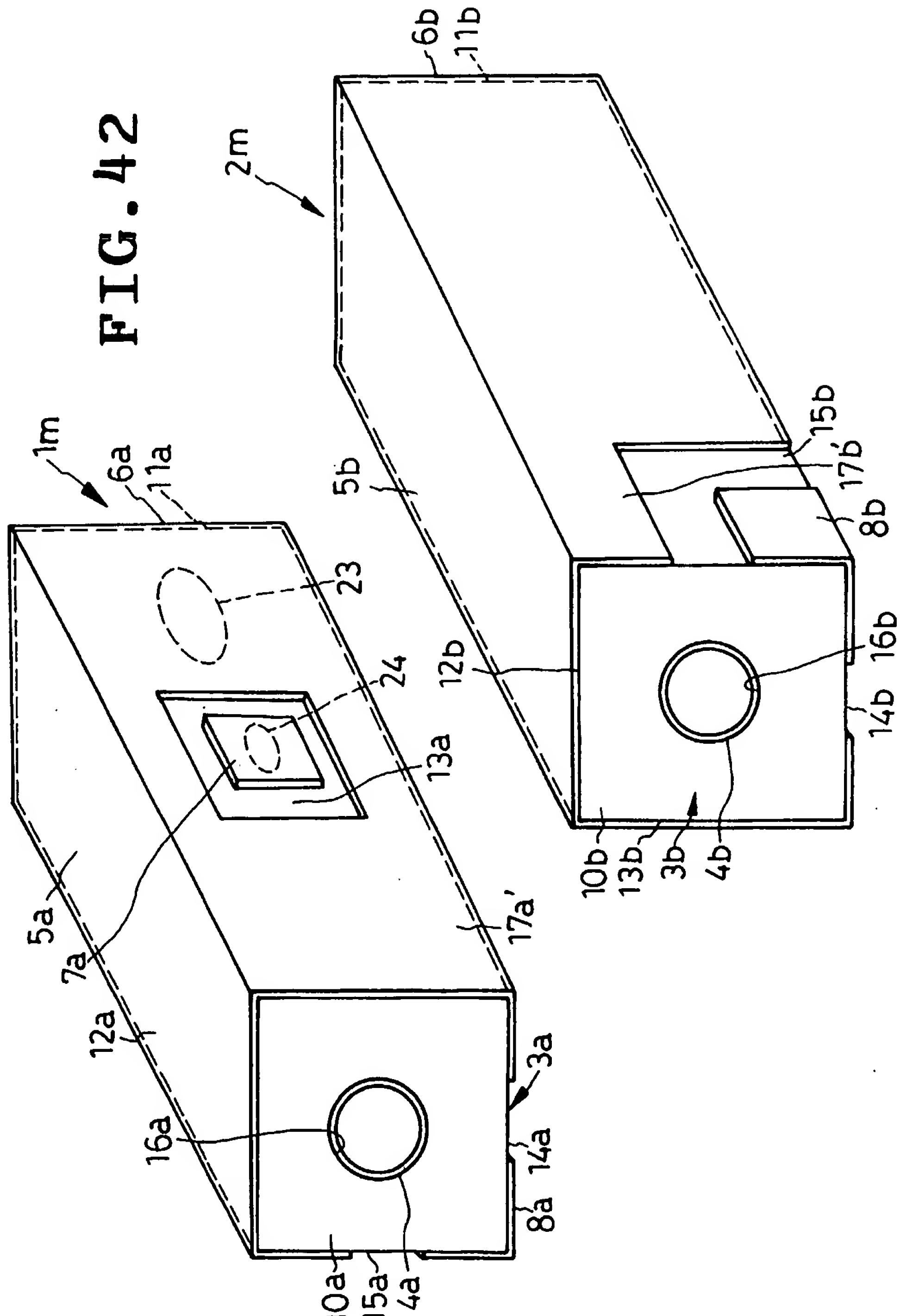
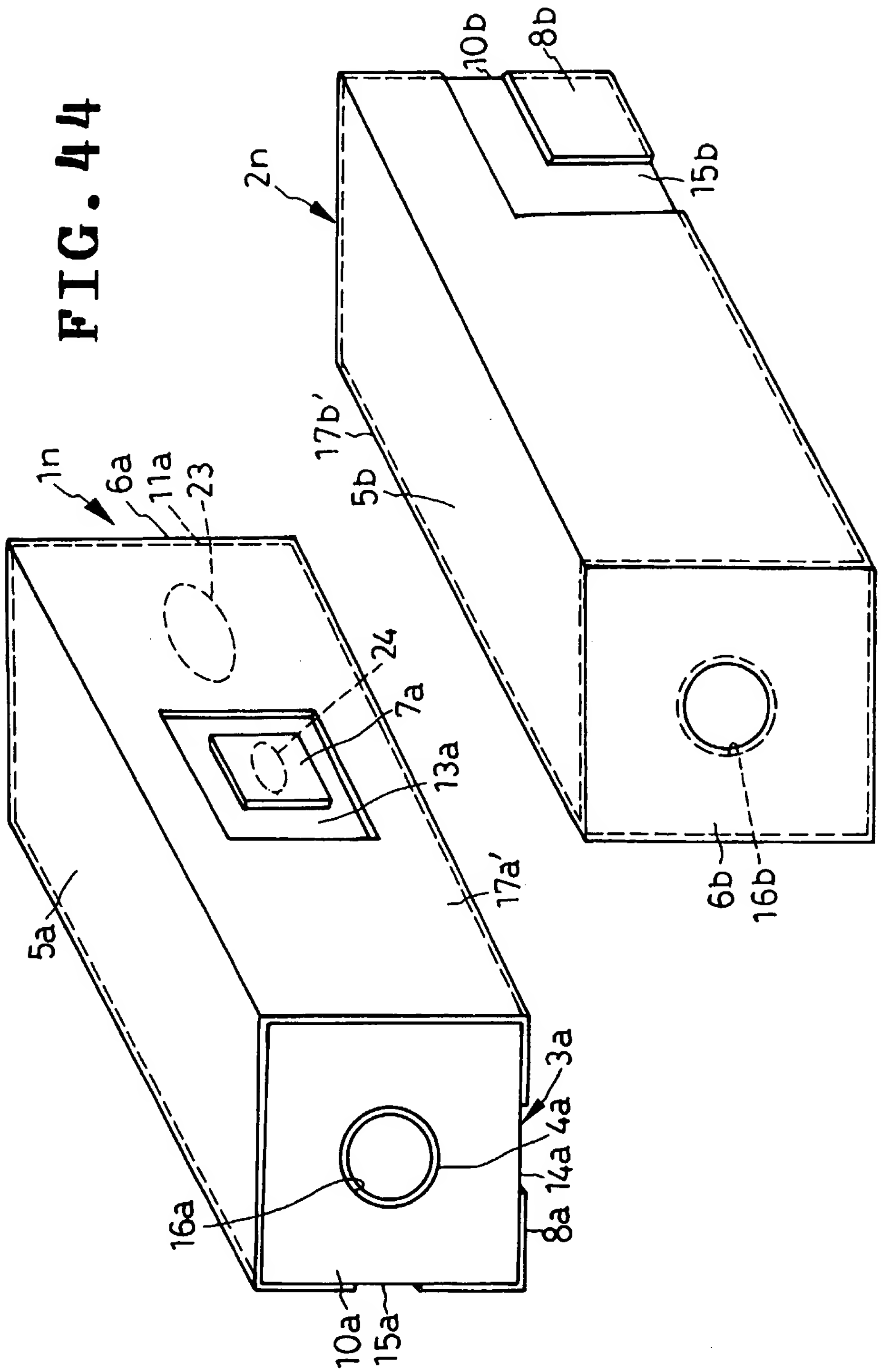

1m
6a
11a
23
24
13a
5a
7a
17a'
12a
16a
3a
14a
8a
10a
15a
4a
2m
6b
11b
5b
15b
17b'
8b
12b
16b
14b
10b
13b
3b
4b

FIG.42

FIG. 44


1n
6a
11a
23
24
7a
13a
17a'
5a
3a
4a
14a
8a
16a
10a
15a
2n
10b
8b
15b
17b'
5b
6b
16b